2025-2026

Caltech Catalog

California Institute of Technology
Pasadena, California 91125
(626) 395-6811

September 2025

The mission of the California Institute of Technology is to expand human knowledge and benefit society through research integrated with education. We investigate the most challenging, fundamental problems in science and technology in a singularly collegial, interdisciplinary atmosphere, while educating outstanding students to become creative members of society.

DISCLAIMER

While every effort has been made to ensure this catalog is accurate and up to date when published, changes affecting its content may occur during the year. Accordingly, the Institute reserves the right to correct or change its policies, rules, regulations, requirements for graduation, course offerings, and any other contents of this catalog at any time, including, but not limited to, admission, registration, tuition and fees, attendance, curriculum and curriculum delivery, the requirements for graduation or degrees, conduct (including discipline for violations of Caltech's Code of Conduct and Institute policies), academic standing, and other rules and regulations affecting the student body.

This Catalog is the main source for students on Institute policy and procedure and contains crucial information on various facets of Institute operations; however, it does not contain all rules and requirements applicable to students. Students will be held accountable to comply with the obligations contained herein and are not exempted from rules and requirements which they did not know existed.

It is the responsibility of the student to keep well-informed with respect to the regulations and requirements in this Catalog, the Code of Conduct, and Institute and Student Affairs policies. Current versions of Institute policies can be accessed at hr.caltech.edu/services/policies. Current versions of the Student Affairs policies can be accessed at studentaffairs.caltech.edu/policies.

In light of the COVID-19 pandemic and its impact on Caltech, the Institute must maintain the flexibility to adapt programs, policies, and on-campus operations for the 2023–24 academic year to meet the needs of the community. For the most up-to-date information on the Institute's health and safety protocols, visit together.caltech.edu.

Please note that the contents of websites that link to online course entries are not part of the official catalog.

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ACADEMIC CALENDAR

2025-2026

First Term 2025

September 18-20
International student orientation

September 21-28
New student check-in and orientation for undergraduates

September 22-26
New student check-in and orientation for graduate students

September 25
Undergraduate Academic Standards and Honors Committee—1 p.m.

September 29
Beginning of instruction—8 a.m.

October 17
Last day for adding courses and removing conditions & incompletes

October 29 – November 4
Midterm examination period

November 10
Midterm deficiency notices due—9 a.m.

November 19
Last day for dropping courses, exercising pass/fail option, and changing sections

November 20 – December 5
Registration for second term, 2025-26

November 27-28
Thanksgiving (Institute holiday)

December 5
- Last day of classes
- Last day to register for second term, 2025-26 without a $50 late fee

December 6-9
Study period

December 10

All faculty meeting—noon to 1 p.m.

December 10–12*
Final examinations, first term, 2025-26

December 12
End of first term, 2025-26

December 13 – January 4
Winter recess

December 17
Instructors' final grades due—9 a.m.

December 24–31
Special release days and floating holidays

December 25
Christmas observed (Institute holiday)

January 1
New Year's Day observed (Institute holiday)

Second Term 2026

January 5
Beginning of instruction—8 a.m.

January 6
Undergraduate Academic Standards and Honors Committee—9 a.m.

January 29
Martin Luther King Day (Institute holiday)

January 23
Last day for adding courses and removing conditions & incompletes

February 4-10
Midterm examination period

February 11
All faculty meeting—noon to 1 p.m.

February 16
Presidents' Day (Institute holiday)

February 17
Midterm deficiency notices due—9 a.m.

February 25
Last day for dropping courses, exercising pass/fail option, and changing sections

February 25 – March 11
Registration for third term, 2025-26

March 11
- Last day of classes
- Last day to register for third term, 2025-26, without a $50 late fee

March 12-15
Study period

March 16–18*
Final examinations, second term, 2025-26

March 18
End of second term, 2025-26

March 19-29
Spring recess

March 23
Instructors' final grades due—9 a.m.

**First due date for final examinations*

Third Term 2026

March 30
Beginning of instruction—8 a.m.

March 31
Undergraduate Academic Standards and Honors Committee—9 a.m.

April 17
Last day for adding courses and removing conditions and incompletes

April 29–May 5
Midterm examination period

May 15
Last day for admission to candidacy for the degrees of Master of Science and Engineer, and for scheduling an examination for the degree of Doctor of Philosophy

May 11
- Midterm deficiency notices due—9 a.m.
- Last day for seniors to remove conditions and incompletes

May 20
Last day for dropping courses, exercising pass/fail option, and changing sections

May 21–June 5
Registration for first term, 2026-27, and for summer research

May 25
Memorial Day (Institute holiday)

May 29
- Last day of classes—seniors and graduate students
- Last day for presenting theses for the degrees of Doctor of Philosophy and Engineer

May 30–June 2
Study period for seniors and graduate students

June 3–5*
Final examinations for seniors and graduate students, third term, 2025-26

June 5
- Last day of classes—undergraduates
- Last day to register for first term, 2026-27, without a $50 late fee

June 6-9
Study period for undergraduates

June 8
Instructors' final grades due for seniors and graduate students—9 a.m.

June 10
- Curriculum Committee—10 a.m.
- All faculty meeting—1 p.m. – 2 p.m.

**First due date for final examinations*

June 10–12*
Final examinations for undergraduates, third term, 2025-26

June 12
Commencement—10 a.m. End of third term, 2025-26

June 17
Instructors' final grades due for undergraduates—9 a.m.

June 24
Undergraduate Academic Standards and Honors Committee—9 a.m.

Summer Term 2026

June 15
Summer Term begins

June 19
Juneteenth (Institute holiday)

July 3
Independence Day (Institute holiday observed)

September 1
Summer Term ends

September 7
Labor Day (Institute holiday)

First Term 2026-2027

September 17-19
International student orientation

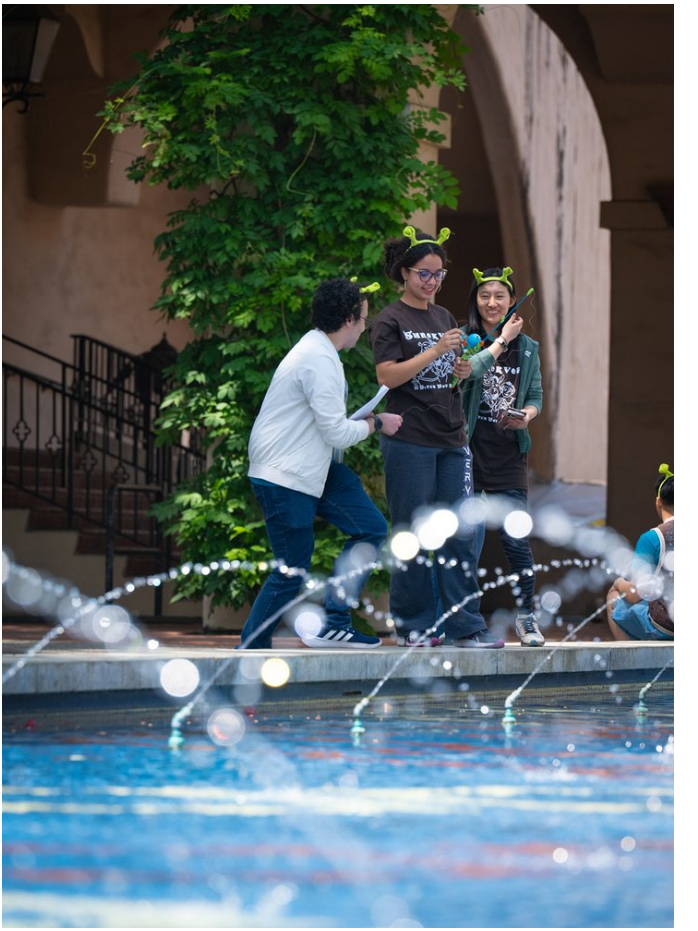
September 20-27
New student check-in and orientation for undergraduates

September 21-25
New student check-in and orientation for graduate students

September 24
Undergraduate Academic Standards and Honors Committee—1 p.m.

September 28
Beginning of instruction—8 a.m.

General Information



INTRODUCTION

Caltech is a world-renowned research and education institute. A purposely small, close-knit, and collaborative community, Caltech empowers the brightest minds to address fundamental scientific questions, develop cutting-edge technologies, and expand the horizons of human knowledge.

The Caltech community embraces an ethos of shared knowledge and believes that the exchange of ideas across diverse backgrounds and perspectives is essential to the advancement of science, engineering, and innovation that benefits society. Students have unparalleled access to top-class researchers and state-of-the-art instrumentation, and more than 90 percent of undergraduates participate in research.

Caltech leads research in areas such as quantum science and engineering, astronomy, advanced computing and artificial intelligence, earth science and sustainability, and biology and health. Institute faculty, alumni, and postdoctoral scholars have earned a total of 47 Nobel Prizes for discoveries including the development of artificial neural networks, the first detection of ripples in space-time, and directed evolution.

The Institute also founded and manages the Jet Propulsion Laboratory, a leader in robotic space exploration, for NASA; operates a global network of astronomical observatories including the Palomar and W. M. Keck observatories; and co-founded and co-manages LIGO, a national facility for gravitational-wave research.

Caltech has one of the nation's lowest student-to-faculty ratios, with some 300 professorial faculty members offering a rigorous curriculum and access to varied learning opportunities to approximately 1,000 undergraduates and 1,400 graduate students.

Caltech is an independent, privately supported institution with a 124-acre campus located in Pasadena, California.

MISSION

The mission of the California Institute of Technology is to expand human knowledge and benefit society through research integrated with education. We investigate the most challenging, fundamental problems in science and technology in a singularly collegial, interdisciplinary atmosphere, while educating outstanding students to become creative members of society.

HISTORICAL SKETCH

In September of 1891, Pasadena philanthropist Amos G. Throop (pronounced Troop) established Throop University, the institution that would eventually become Caltech.

Throop University opened its doors with 31 students and a six-member faculty. Throop might have remained simply a good local school had it not been for the arrival in Pasadena of astronomer

George Ellery Hale. The first director of the Mount Wilson Observatory, Hale became a member of Throop's board of trustees in 1907 and began molding the school into a first-class institution for engineering and scientific research and education. Hale would be joined later by chemist Arthur A. Noyes and physicist Robert A. Millikan.

In 1920, the school was renamed the California Institute of Technology. The enrollment was nine graduate students and 359 undergraduates, with a faculty of 60; a decade later there were 138 graduate students, 510 undergraduates, and a faculty of 180. At the present time there are some 1,000 undergraduates, 1,400 graduate students, 300 professorial faculty, and more than 600 postdoctoral scholars.

Caltech has more than 25,000 living alumni all over the world, many of them eminent in their fields of engineering, science, law, medicine, academia, entrepreneurship, and more.

Caltech's divisional structure, which began to coalesce in 1926, today comprises the Division of Biology and Biological Engineering (BBE); the Division of Chemistry and Chemical Engineering (CCE); the Division of Engineering and Applied Science (EAS); the Division of Geological and Planetary Sciences (GPS); the Division of the Humanities and Social Sciences (HSS); and the Division of Physics, Mathematics and Astronomy (PMA). To learn more about Caltech's history and the people behind the Institute's success, visit archives.caltech.edu

EDUCATION AND RESEARCH

Students at Caltech work toward undergraduate and graduate degrees alongside their intellectual equals in an academic environment that emphasizes interdisciplinary teamwork, critical thinking, mutual support, and a deep understanding of core concepts and principles across fields.

Caltech students, faculty, and postdoctoral scholars are addressing fundamental scientific questions and pressing societal challenges. Together, they are expanding our understanding of the universe, shifting paradigms, launching new fields, and inventing the technologies of the future.

Caltech is home to more than 50 research centers and institutes. Some 90 percent of Caltech undergraduates participate in research during their time here.

UNDERGRADUATE PROGRAMS AND RESEARCH

Caltech offers undergraduates 26 majors (called "options") and 17 minors across the six academic divisions. The most popular options are computer science, chemical engineering, electrical engineering, mechanical engineering, and physics. Caltech also offers interdisciplinary programs in applied physics, biochemistry, bioengineering, computation and neural systems, control and dynamical systems, environmental science and engineering, geobiology and astrobiology, geochemistry, and planetary astronomy.

The Institute offers the opportunity for qualified students to engage in research early in their careers under the supervision of a faculty member. There are four principal avenues for undergraduate research: the senior thesis, the Summer Undergraduate Research Fellowships (SURF) program, research courses for academic credit, and research for pay under a faculty member's grant or contract.

The senior thesis involves original research under the mentorship of a faculty member, an effort that develops research, writing, and presentation skills that together provide an excellent preparation for future graduate studies and/or professional life.

The SURF program provides continuing undergraduate students the opportunity to work on an individual research project in a tutorial relationship with a mentor, usually a member of the Caltech/JPL research community, but occasionally a faculty member at another college or university. The work is carried out during a 10-week period in the summer, after which SURF students submit a written report describing the project, methods, and results of their work.

Most options offer undergraduate research courses in order to encourage research participation during the academic year; students should consult listings and descriptions of opportunities.

In some circumstances, faculty will hire students to conduct research. Students should discuss this option with a prospective mentor. Students with work-study financial aid should also contact Caltech's Career Achievement, Leadership, and Exploration (CALE) about how to apply funding to research positions.

Learn more about undergraduate programs and research at sfp.caltech.edu/.

GRADUATE PROGRAMS AND RESEARCH

Students can enroll in Master of Science, Degree of Engineer, Doctor of Philosophy, BS/MS, and MD/PhD degree programs; the majority of graduate students are enrolled in the PhD program.

The academic work of the Institute is organized into six divisions: Biology and Biological Engineering (bbe.caltech.edu); Chemistry and Chemical Engineering (cce.caltech.edu); Engineering and Applied Science (eas.caltech.edu); Geological and Planetary Sciences (gps.caltech.edu); Humanities and Social Sciences (hss.caltech.edu); and Physics, Mathematics and Astronomy (pma.caltech.edu).

Graduate study at the Institute is divided further into a number of individual graduate options (degree programs), which are supervised by those professors whose interests and research are closely related to the area of the option. Entering graduate students are admitted into one of these options. The most popular options for graduate work are chemistry, physics, electrical engineering, and biology. Learn more at gradoffice.caltech.edu.

ACADEMIC PARTNERSHIPS

Caltech maintains an array of external partnerships with other institutions in Southern California. These partnerships provide pre-med students with opportunities to work in area hospitals and train with practicing clinicians; allow students to participate in ROTC through a joint program with USC; and offer a 3/2 dual degree for students from 13 select liberal-arts colleges. Caltech undergraduate students can cross-register at Occidental College and Art Center College of Design, and the Institute maintains relations with research partners such as the Scripps Institution of Oceanography at UCSD. Undergraduate students can also study abroad in Cambridge, Copenhagen, Edinburgh, London, Paris, Melbourne, or the University of Chicago during their junior or senior years For graduate students, joint programs between Caltech and both the USC Keck School of Medicine and the UCLA David Geffen School of Medicine grant MD/PhD degrees.

FACULTY RESEARCH

The contributions of Caltech's faculty have earned national and international recognition. Caltech was elected to the Association of American Universities (AAU) in 1934 and remains a research university with "very high" research activity, primarily in STEM fields. Research is central to Caltech, and the Institute manages over $400 million in sponsored awards annually. Its largest federal funding agencies are the National Aeronautics Space Administration (NASA), National Science Foundation (NSF), Department of Health and Human Services, Department of Defense, and Department of Energy. More than a quarter of Caltech's active and emeritus faculty members are members of the National Academy of Sciences, Engineering, and Medicine and/or are fellows of the American Academy of Arts and Sciences. Caltech receives more invention disclosures and holds more patents per faculty member than any other university in the United States.

POSTDOCTORAL AND SENIOR POSTDOCTORAL SCHOLARS

More than 550 early-career scientists and engineers conduct research at Caltech as postdoctoral scholars. In addition, JPL hosts postdoctoral scholars whose studies cover many aspects of Earth, planetary, astrophysical, and technology research. All scholars work under the supervision of professorial faculty members or JPL researchers.

RESEARCH CENTERS AND INSTITUTES

Research centers and institutes across campus bring together scientists and engineers to collaborate and add innovative and diverse perspectives to tackle society's most pressing challenges. Among those centers and institutes are:

- the Tianqiao and Chrissy Chen Institute for Neuroscience at Caltech, which seeks to deepen our understanding of the brain and how it works;
- the Beckman Institute, which develops methods, instrumentation, and materials for fundamental research in chemistry and biology;
- the Kavli Nanoscience Institute, which advances cross-disciplinary research in the areas of nanoscience and nanotechnology;
- the Donna and Benjamin M. Rosen Bioengineering Center, which encourages intensive, fruitful collaborations between bioengineering researchers;
- the Resnick Sustainability Institute, which fosters advances in energy science and technology through research, education, and communication;
- the Richard N. Merkin Institute for Translational Research

Learn more about Caltech's research centers and institutes at caltech.edu/research/centers-institutes.

ON-CAMPUS ACADEMIC RESOURCES

Center for Teaching, Learning, and Outreach (CTLO)
The Center for Teaching, Learning, and Outreach (CTLO) supports Caltech's multifaceted educational efforts, including the design and instruction of undergraduate and graduate courses and curricula, formal and informal student learning, and educational outreach partnerships with K–12 teachers and students. The CTLO is committed to advancing evidence-based, inclusive practices through our programs and services, and to fostering innovation based on this foundation. CTLO focuses on:

Instructor Support: Supporting effective course design and teaching methods for university faculty and teaching assistants (TAs). Topics regularly addressed through individual consultations, training programs, workshops, and courses include in-class techniques, choice and use of instructional technologies, feedback on teaching, and discipline-based educational research.

Student Learning: Fostering opportunities for students to grow as teachers, mentors, and leaders. In addition to advising students on teaching and outreach-related projects, CTLO oversees the Caltech Project for Effective Teaching (CPET), a graduate student-led community offering seminars and Certificates of Interest and Practice in University Teaching, and collaborates with the undergraduate Academics and Research Committee (ARC) on course improvements, course ombuds, and other initiatives.

Educational Outreach: Helping faculty and students to develop K–12 outreach programs, including collaborations with schools and districts in Pasadena and Greater Los Angeles. CTLO assists faculty on grant proposals with educational components, convenes educational outreach coordinators from across Caltech's divisions, runs signature educational outreach programs for K–12 students and teachers during the summer and year-round, and serves as an

interface for partner organizations offering K–12 opportunities at Caltech.

Learn more at ctlo.caltech.edu.

Hixon Writing Center (HWC)

The Hixon Writing Center (HWC) promotes excellence in writing and communication. The HWC operates on the premise that writing is a mode of discovery and learning as well as a tool for communication, and thus strong writing skills are fundamental to inquiry, learning, and success across disciplines.

The HWC works actively with Caltech students, faculty, and the Caltech community. The HWC offers students the opportunity to meet one-to-one with professional and peer tutors to discuss works-in-progress. These sessions help students accomplish short-term goals while they also promote the acquisition of skills that are valuable for long-term success. HWC staff members are available to consult with Caltech faculty and TAs about best practices for incorporating, designing, and responding to writing assignments in courses across all disciplines. Finally, the HWC sponsors events and creates resources that address varied aspects of academic writing, with a particular focus on academic STEM writing.

The HWC is a part of the Division of the Humanities and Social Sciences, and it is funded in part by a generous donation from Alexander P. and Adelaide F. Hixon. Learn more about current support and programming at writing.caltech.edu.

Caltech Library

The Caltech Library advances the Institute's mission to expand human knowledge by catalyzing information discovery and sharing. The Library maintains extensive research collections, a variety of study spaces, state-of-the-art knowledge-management platforms, and a user-focused program of instruction and outreach.

The Sherman Fairchild Library (SFL) is the main library on campus. SFL is usually open 7 days a week late into the evening and offers a range of collaborative and private study spaces including five bookable group study rooms. All textbooks assigned for courses are available for short-term use through the Library's Course Reserves service. The Library's interlibrary loan service, DocuServe, is located on the first floor of SFL. Users can obtain books and articles not owned by Caltech Library at no charge. Most articles are fulfilled within 24 hours, and books are typically delivered within one week.

SFL is complemented by three branch libraries: Dabney (Humanities and Social Sciences), Cahill (Astrophysics), and North Mudd (Geology and Planetary Sciences). Caltech Hall also houses additional collections, along with two specialized Library locations: the 9th floor, and the TechHub. The 9th floor classroom area is a flexible collaboration and study space with large displays. Room 907 is a bookable meeting or teaching space, and the north side of Caltech Hall provides ample study carrels and collaboration spaces. On the first floor, the TechHub provides 3D printing, large-format printing and scanning services, and loans of laptops and other electronics.

The Caltech Library hosts several digital repositories including CaltechAUTHORS, for research papers, monographs, and other scholarly publications; CaltechTHESIS, for theses and dissertations; CaltechCampusPubs for publications about campus life; and CaltechDATA, for primary research data and computer code.

Visit the Library's website,library.caltech.edu, to access Library collections and services or to request research assistance.

Archives and Special Collections

The Caltech Archives and Special Collections facilitates understanding of Caltech's role in the history of science and technology, and of the research and lives of its faculty, staff, and students. The Archives collects, organizes, preserves, exhibits, and makes available for research the papers and other materials that document this history, both tangible and virtual. Collections include the personal and professional papers of Caltech faculty and alumni; Caltech records, publications, and websites; scientific instruments and other artifacts; photographs; fine art; and rare books from the Scientific Revolution to the present. These collections are available to both the Caltech community and outside researchers; contact the Archives at 626-395-2704 or archives@caltech.edu to arrange an appointment. More information, including guides to many collections and digital access to some, can be found at archives.caltech.edu.

EDUCATIONAL PHILOSOPHY & LEARNING OUTCOMES

Caltech provides an outstanding education that prepares students to become world leaders in science, engineering, academia, industry, and public service. The Institute aims for these educational outcomes:

- Graduates can analyze, synthesize, and communicate ideas.
- Graduates demonstrate integrity, personal and professional responsibility, and respect for others.
- Bachelor of Science graduates can identify, analyze, and solve challenging problems within and across science and engineering disciplines.
- Bachelor of Science graduates can apply their analytic skills to other areas of knowledge and understand issues important in our society.
- Master of Science graduates can apply advanced knowledge in a specialized area in preparation for their professional careers.
- Doctor of Philosophy graduates can independently identify, analyze, and solve fundamental research problems with breadth and depth.

JET PROPULSION LABORATORY

Founded by Caltech researchers in the 1930s, the Jet Propulsion Laboratory (JPL) has been managed by Caltech for NASA since our nation's civilian space agency was established in 1958.

The Lab is a leader in robotic space exploration that sends rovers to Mars, probes to the far reaches of the solar system, and satellites into orbit. In addition to its active space missions, JPL's research and technology development programs advance our understanding of Earth and beyond. Its spacecraft have flown to every planet in the solar system, the Sun, and into interstellar space.

As an actively integrated and interconnected community of innovators, problem solvers, and practitioners, Caltech and JPL together offer NASA an extended array of capabilities integrated across all levels of science and engineering. Together, they also provide the technical and administrative capacity to help NASA deliver projects and programs with an extraordinary potential to expand U.S. technological leadership and forever shape our understanding of the universe and our place within it.

Learn more at jpl.nasa.gov.

STUDENT LIFE

UNDERGRADUATE STUDENT RESIDENCES

Seven of the undergraduate student residences are situated on either side of the Olive Walk near the southeastern end of the campus. The original four—Blacker, Dabney, Fleming, and Ricketts—were built in 1931 from the plans of Mr. Gordon B. Kaufmann, in the Mediterranean style to harmonize with the adjacent Athenaeum. The other three, designed by Smith, Powell and Morgridge, were completed in 1960, and are named Lloyd, Page, and Venerable.

Each of these seven residences is a separate unit with its own dining room and lounge, providing accommodations for between 65 and 100 students, depending on the facility. Each has its own elected officers; a long history of shared governance gives students the ability to represent their needs in their own living environments. Residential Life Coordinators (RLCs) are specially trained full-time university employees specializing in college student development, community building, counseling, and crisis intervention. The RLCs supervise the Resident Associates (RAs) on programming and overall student wellness. The RLCs also assist Housing with the management and daily operations of the residences. Each residence has one or more RA, who are typically graduate students. Mail is delivered daily to the student mailboxes. Students should use their mailbox number, California Institute of Technology, Pasadena, CA 91126, to facilitate handling of mail at the campus post office. For more information, please visit housing.caltech.edu.

Avery House
Made possible by a gift from trustee R. Stanton Avery, this undergraduate residence and innovative residential complex was designed by Moore, Ruble, Yudell, and completed in September 1996. Located at the north end of the campus, Avery has an RLC, two RAs, two faculty apartments, and rooms for about 136 undergraduates. Its dining facilities, meeting rooms, lounges, and library are designed to encourage informal faculty-student interaction and to attract all members of the campus community to join in this interaction. Avery hosts programs and social events that facilitate involvement between residents and faculty in residence.

Bechtel Residence
Established in the fall of 2018 and located at the northeast edge of campus, the Bechtel Residence is the first residence to open on campus since 1996. Bechtel is named in honor of Caltech life trustee Stephen D. Bechtel, Jr., the founder of the S. D. Bechtel Foundation.

The 95,000-square-foot residence is a multigenerational residence open to all undergraduates with: 211 student bedrooms arranged as singles and in suites; six RA and one RLC apartments; and two faculty-in-residence apartments. Bechtel was intentionally designed to provide the community with the greatest flexibility to maximize space as well as to encourage broader interaction, engagement, and residential life programming among residents. The facility includes three kitchens; eight common areas/study rooms; several laundry rooms; a 400-seat dining hall and servery; and support spaces.

Summer Housing
Caltech will extend a License Contract to those individuals who satisfy the following criteria: (1) they have been approved by the Housing Office and the Undergraduate Dean's Office; (2) they are eligible to enroll for the upcoming Fall Term by no later than the June UASH meeting; and (3) they are in good standing with both the Bursar's Office and the Institute overall. Individuals must satisfy this criteria for the duration of the License Contract. If a Caltech student becomes ineligible to enroll, or is no longer in good standing with the Bursar's Office, or in good standing with the Institute, or in good standing with their Institute-approved summer program, their License Contract will be automatically revoked. UASH meeting dates and petition deadlines can be found at registrar.caltech.edu/current-students/uash.

STUDENT RESOURCES AND ACTIVITIES

Hameetman Center
The Hameetman Center, which opened in 2019, is a new campus center built on the site of the former Winnett Student Center. The Hameetman Center replaces Winnett as Caltech's central community gathering place. The 24,000-square-foot two-story center is named in honor of the Hameetman Foundation and Caltech trustee Fred Hameetman (BS '62) and his wife, Joyce, who provided the initial funding to initiate the design of the reimagined campus hub. It features

a large public lounge, an expanded Red Door Marketplace, the Caltech Store, music rehearsal facilities, student club rooms, a multipurpose room, and a conference room. The rehearsal facility is made possible thanks to a gift from Emeritus Professor of Theoretical Physics Steven Frautschi and his wife, Mie.

Student and Family Engagement

The Office of Student and Family Engagement (SFE) has responsibility for the oversight of Caltech's residential programs, including programs carried out in the undergraduate houses, graduate student residences, and the Bechtel and Marks-Braun communities. SFE works collaboratively with the Residential Life Coordinators, Resident Associates, the Interhouse Committee, and other groups to ensure that student leaders in all our residential communities are trained and that there are programs in place to support their development. This is part of the shared governance that is central to the Caltech residential experience. The residential experience also includes members of the faculty who live in the undergraduate residences. The Faculty in Residence (FIR) Team establishes an academic life and culture in Bechtel and Avery House. FIRs bridge the classroom experience by hosting regular conversations over dinner and develop specialized academic programing, which can include: extracurricular activities, tours and excursions, cooperative community service projects, special events, and guest speaker programs.

In keeping with Caltech's values of integrity and fairness, students and recognized student organizations, all including but not limited to student houses and residences, student groups, and recreation and athletic teams, are expected to follow all Institute policies. These include but not limited to, Student Affairs policies, the Honor Code Handbook, and the Caltech Code of Conduct, and divisional policies. These policies, including the review processes that guide corrective actions in the case of alleged violation(s), may be found at deans.caltech.edu/HonorCode

The Student Activities Center

The Student Activities Center (SAC) is located in the basement of the south undergraduate housing complex and is open for student use 24 hours a day. The SAC provides office space for the officers of the undergraduate student government, working space for student publications, rehearsal space for musical activities, and space for many other student-oriented functions.

Whether students are interested in music, publications, student government, gaming, photography, or simply finding a room for their group to meet in, the SAC will probably have what is needed. The center also houses the South House laundry room and has several club rooms, a small library, a shop, and a movie screening room—most are open 24 hours.

Faculty-Student Relations
Faculty-student coordination and cooperation with regard to campus affairs are secured through the presence of students on faculty committees, by faculty-student conferences, and by other mechanisms.

First-Year Advisers
Each member of the first-year class is assigned a faculty adviser and is a member of a small advising group. The adviser follows the first-year student's progress and provides advice on any questions or problems that the student may have.

Option Advisers
Each member of the three undergraduate upper classes is assigned an option adviser, a faculty member in the option in which the student is enrolled. The adviser takes an interest in the student's selection of courses and progress toward a degree, and, eventually, in assisting the student toward satisfactory placement in industry or in graduate school. Normally, the association between student and adviser is established before the beginning of the sophomore year and continues through graduation.

Athletics, Recreation, and Instruction
Caltech supports an extensive program of competitive athletics. As a member of NCAA Division III and the Southern California Intercollegiate Athletic Conference, Caltech participates in intercollegiate competition in 20 sports—10 each for men and women. All teams compete during a regular season, with many also competing or qualifying for the conference tournament in their respective sport. Individual scholar-athletes and teams distinguishing themselves can earn the privilege of participating in NCAA regional and national championships.

Caltech also sponsors vigorous club sports programs and intramural competition. Club sports include Ultimate Frisbee, volleyball, badminton and soccer. Intramural competitions are contested by residence house teams in several sports, including soccer, dodgeball, kickball, Ultimate Frisbee, basketball, volleyball, and floorball. Approximately 25 percent of Caltech undergraduates participate in intercollegiate athletics and over 80 percent participate in some form of organized athletic competition each year.

Outdoor athletic facilities include a brand-new turf mixed-use baseball and soccer field, a second natural grass mixed-use field, an all-weather running track, eight tennis courts, and two 25-yard, eight-lane swimming pools. Indoor facilities include two full-size gymnasiums; four racquetball courts, two squash courts; a 5,000-square-foot weight room, satellite weight room and more than 55 pieces of cardio-respiratory equipment, including treadmills, exercise bikes and ellipticals; and a large multipurpose room for dance/aerobics, martial arts and a variety of group fitness courses.

The department is also responsible for management of Caltech's recreation programs and physical education curriculum.

More information can be found at gocaltech.com.

Interhouse Activities

The president of each undergraduate house represents that house on the Interhouse Committee (IHC), which helps to handle matters affecting the houses, in conjunction with staff from Student Affairs. Members of the IHC are expected to be enrolled and in good standing, both academically (eligible, and not on probation) and disciplinarily (not on probation), during their tenure in office. The IHC works in conjunction with the Athletics, Recreation and Instruction department to conduct intramural competitions as described above, and conducts its own Discobolus Trophy competition, in which a house may challenge the house holding the trophy to a mutually agreed upon contest.

ASCIT

The undergraduate student body forms the membership of a corporation known as the Associated Students of the California Institute of Technology, Inc., or ASCIT. Governed by a board of directors consisting of six elected officers, it is involved in many aspects of student life; oversees publication of The Tech, our undergraduate student newspaper; the Big T yearbook; a literary magazine called Totem; and the Little t, which provides lots of helpful information to incoming students. A directory, along with other student information, such as campus positions, links to the Interhouse Committee (IHC) and Academics and Research Committee (ARC), and other helpful information is available online at donut.caltech.edu.

Besides overseeing student publications and coordinating activities and policies, the ASCIT Board of Directors administers the corporation's finances. ASCIT sponsors a wide variety of special-interest clubs and programs. The student government is active in campus affairs. The student members of standing faculty committee ensure that undergraduate opinion is considered seriously. Excellent informal relations between students and faculty and between students and administration promote discussion of mutual concern and goodwill. Student-faculty conferences are held every other year and serve to promote communication mainly around academic topics.

Graduate Student Council

The Graduate Student Council (GSC) is the student government for Caltech graduate students. It is the mission of the GSC to maximize the quality of life for the graduate student community at Caltech. The GSC Board of Directors interacts with the Institute's administrative bodies and is formed of subcommittees dedicated to academic support, advocating graduate student issues, sharing student news, and organizing social events.

Student Leadership Expectations
Graduate and undergraduate student leaders who are in either elected or appointed positions must be enrolled and in good standing with the Institute.

Honor System
The Honor Code, embodied in the phrase "No member shall take unfair advantage of any other member of the Caltech community," is the fundamental principle of conduct for all students and extends to all phases of campus life, including scholastic and extracurricular activities, relations among students, and relations between students and faculty. The Honor System is the most important tradition of the undergraduate student body. The Board of Control (Board), which is composed of elected student representatives, is charged with monitoring the academic Honor System for undergraduates, investigating course work violations, and making recommendations to the dean of undergraduate students. The purpose, composition, duties, and procedures of the Board, as well as the roles and responsibilities of the deans, faculty, vice president for student affairs, complainants (students reporting suspected violations), respondents (those against whom an allegation of an academic Honor System violation is made), witnesses, and other participants in the process, are set forth in Article XIII of the Associated Students of the California Institute of Technology bylaws.

The Conduct Review Committee, composed of students, faculty, and staff, hears cases involving non-academic Honor Code and Institute policy violations for undergraduate students, and also makes recommendations to the dean. At their discretion, the dean of undergraduate students, or their designee, may directly handle a matter also involving the Honor System, the Code of Conduct, and Institute Policies for undergraduate students. The Honor Code Handbook, a resource for undergraduate students, is available online at deans.caltech.edu/HonorCode.

The Honor System is also an important part of graduate student life. The dean of graduate studies is responsible for reviewing and making decisions concerning alleged Honor Code violations with respect to course-work. The Graduate Honor Council (GHC) serves as a consultative resource to the dean. At their discretion, the dean of graduate studies may request that the GHC investigate and hear a case, and provide its recommendations to the dean for final review and decision. All Members of the Graduate Honor Council must be in good standing with the Office of Graduate Studies and must attend a formal training before they may serve on a case. Examples of Honor Code violations include, but are not limited to, plagiarism, violations of the collaboration policy in a class, and/or using resources that were strictly prohibited for homework and/or exams. Incidents that are not handled by the dean of graduate studies include accusations of research misconduct, which are handled by the Office of Research Compliance; grade disputes, which are handled by the office of the provost. Institute Policy violations are handled by the office of the dean of graduate studies or the appropriate administrative

organization.

Student Body Publications

The publications of the student body include a weekly paper, *The California Tech*; an undergraduate research journal, *CURJ*; a literary magazine, *Totem*; a student handbook, the *Little t*, which gives a survey of student activities and organizations and serves as a campus directory; a yearbook, *Big T*; an online undergraduate research opportunities handbook, *UROH*; and Caltech Letters, an online campus publication designed to let students talk about their research and their viewpoints on science with the broader world. These publications, staffed entirely by students, provide an opportunity for interested students to obtain valuable experience in creative writing, photography, artwork, reporting and editing, advertising, and business management.

Performing and Visual Arts

The Institute provides directors and facilities for choirs, concert band, jazz band, symphony orchestra, numerous chamber music ensembles, guitar classes, a theater program, ceramics and studio arts classes. These activities are centered in the Music and Theater Arts houses on Hill Avenue along the eastern edge of campus.

Student Clubs

All student clubs must be officially recognized in order to be in and remain in good standing with the Institute. To become officially recognized, the club must annually apply for recognition. You will find details regarding this process outlined in the Student Club Handbook, which is available on the Office of Student and Family Engagement website (sfe.caltech.edu).

Once the club is officially recognized, it may plan on maintaining that recognition for the duration of the current academic year. The details of how to remain in good standing with the Institute are outlined in detail within the Student Club Handbook. These details include club oversight, privileges, responsibilities, finances, and other very important information. A recognized club will receive the following privileges: the ability to recruit members; advertise events; secure funding; conduct officer elections; provide trainings and use Institute facilities for meetings and events. Additional, key elements of club recognition include but are not limited to, having an advisor, an appropriate purpose, and a leadership infrastructure. Note that only recognized clubs will be allowed to participate in the annual Club Fair.

In keeping with Caltech's values of integrity and fairness, students and recognized student organizations, all including but not limited to student houses and residences, student groups, and recreation and athletic teams, are expected to follow all Institute policies. These include but not limited to, Student Affairs policies, the Honor Code Handbook, and the Caltech Code of Conduct, and divisional policies. These policies, including the review processes that guide corrective actions in the case of alleged violation(s), may be found at deans.caltech.edu/HonorCode

Caltech Center for Inclusion & Diversity (CCID)
The mission of the CCID is to enhance the experience of all Caltech community members holistically through **education, advocacy, cultural exchange, leadership development,** and **coalition building**. We serve as a hub of resources and partner with various stakeholders to advance inclusion, diversity, equity, and accessibility (IDEA) at the Institute and within the community.

The CCID hosts various events throughout the year, including affinity spaces, cultural exchange opportunities, *cultural holiday celebrations, LGBTQIA+ community celebrations, identity development programs, dialogues, and leadership workshops.* **CCID programming, support structures, and campus organizations are open to anyone in the campus community, regardless of race, national origin, sex, gender identity, sexual identity, and/or any other protected characteristic.**

Our CCID **signature programs and events** are the *First-Year Success Research Institute (FSRI), Mellon Mays Undergraduate Fellowship (MMUF), the STEMinar Speaker Series, the Unpacking Hate Series, the Dine & Dialogue Series, and the annual Celebration of Excellence event.*

If you are interested in getting involved with CCID, please visit the center's website at ccid.caltech.edu.

Caltech Y
The Caltech Y is a student-driven nonprofit organization on campus. Founded by students for students, the Y challenges the Caltech community to see the world with a broader perspective and a deeper understanding of social issues. Y programs focused on community service and activism, outdoor adventures, social activities, and cultural events encourage students to become active participants in the world. With the help of Y staff, student leaders plan and lead events, trips, and initiatives on campus and beyond. Some of the many Y programs include the Rise tutoring program, the Y hike in the California Sierras, Alternative Spring Break, Make-a-Difference Day, World Fest, the Student Activism Speaker Series, and the D.C. Science Policy Trip. The Y also provides services to the Caltech community, such as low-cost audio visual and camping equipment rentals, discounted tickets, and much more. For more information about student planning meetings, email caltechy@caltech.edu or check out our website at caltechy.org. Follow us on Facebook at facebook.com/caltechy and Instagram at instagram.com/caltechy.

Religious Observation
Caltech has a quiet room for prayer, mediation, quiet reflection and religious observation. The quiet room is located in the Hameetman Student Center. For information about religious clubs, see the Student Clubs website at sfe.caltech.edu.

Special Meals
If you have a dietary restriction that requires a special request, please contact Caltech Dining Services at dining@caltech.edu. If your restriction rises to the level of a disability, please visit the Caltech Accessibility Services for Students (CASS) website at cass.caltech.edu to request accommodation.

Registration for Student Sponsored Events
Student events, including parties, activities, and programs that are hosted by a house, residence, or student club/organization, are a privilege at Caltech and are part of the social framework of the Institute, but must be conducted in a safe and legally compliant manner. We expect the student body to follow laws, polices, guidelines for events, use common sense, and good judgement. All events must be registered per event registration requirements; for additional information and to complete your Student Event Registration online, visit spa.caltech.edu.

Student Auxiliary Services
The Student Auxiliary Services, Gift & Technology Store (caltechstore.caltech.edu) is located on the first floor of the Hameetman Center. Established in the 2018–2019 academic year with a lead gift from The Hameetman Foundation, the Hameetman Center (formerly the Winnett Student Center) is now renamed in the Foundation's and Fred Hameetman (BS '62) and his wife, Joyce's honor. Owned and operated by the Institute, the store serves the students, faculty, and staff, carrying a stock of Caltech authors' books, insignia merchandise, gift items, school supplies, computer hardware, and accessories that support Caltech's educational and research mission. Also located on the first floor of the Hameetman Center is the redesigned Red Door Marketplace that offers freshly brewed coffee and tea, full menu, and bakery items.

STUDENT WELLNESS SERVICES

GENERAL INFORMATION

Student Wellness Services is committed to supporting the health and emotional well-being of Caltech students. Through individualized treatment planning, consultation, and outreach, we provide direct services and community-level interventions to improve student wellness and allow students to focus on their pursuit of academic success and holistic development. All enrolled students, regardless of insurance coverage, are eligible for basic medical and psychological care, crisis counseling, and occupational therapy at Student Wellness Services, through payment of the health fee. Students who require specialty or longer-term care beyond the scope of what Student Wellness Services provides will be referred to community providers using their health insurance; costs associated with this care are the responsibility of the student. A full description of the range of services

and programs offered by Student Wellness Services can be found at wellness.caltech.edu.

HEALTH FORMS

Matriculating and matriculated students are required to submit entrance health forms that include medical and immunization history. Information regarding immunization requirements and the completion of the health forms are posted on the Student Wellness Services website. Additional immunization requirements may be adopted by the Institute as necessary. Matriculating students will receive access to the Student Health Portal to enable secure online upload of the forms. Health forms must be received in accordance with the dates and deadlines established by Student Wellness Services and set forth on the Student Wellness Services website. Failure to meet these requirements will result in a registration hold, withdrawal from registered classes, and the inability to register for future classes until submitted health forms are complete and fully compliant with Student Wellness Services requirements.

STUDENT HEALTH INSURANCE

Students have the option to waive the Caltech student insurance plan during the waiver period each year, provided they show proof of adequate alternative coverage. Students will be automatically enrolled in the Caltech plan if a waiver is not submitted. The Caltech Anthem plan provides coverage (with deductible and copay) for most hospital and surgical costs, as well as the cost of outpatient treatment for injury, illness, and psychotherapy. Students must be enrolled in order to maintain eligibility for coverage. Students on an approved medical leave can continue coverage for up to one year; the cost of the plan premiums will be the responsibility of the student. Complete coverage and exclusion details can be found here: hr.caltech.edu/studentbenefits. If the Caltech plan has been waived, students are advised to ensure that their alternative coverage provides access to medical and mental health providers close to campus.

CALTECH ACCESSIBILITY SERVICES FOR STUDENTS (CASS)

GENERAL INFORMATION

Caltech Accessibility Services for Students (CASS) seeks to provide students with disabilities with equal access to all Institute programs, activities and services. Caltech is committed to maintaining a diverse academic community, and welcoming individuals with a broad spectrum of talents and experiences to its campus and programs. Students with disabilities, actively participating in all aspects of the Caltech experience, are an essential part of that diversity.

CASS will make every reasonable effort to provide academic adjustments and other reasonable accommodations to otherwise

qualified students with known disabilities, including temporary conditions, consistent with Caltech's obligations under applicable law; including the Americans with Disabilities Act (ADA) of 1990, and Section 504 of the Rehabilitation Act of 1973.

CASS will maintain the confidentiality of all student records as required by law, and only shares necessary information with faculty, staff, and housing when given a student's consent. Disability accommodations will not appear on a student's transcript.

Students may visit the CASS website at cass.caltech.edu for more information about the process of registering for disability accommodations and documentation guidelines. Completed CASS applications may take up to 30 days to process, so students are encouraged to submit applications in a timely manner.

CALTECH CARE TEAM

GENERAL INFORMATION

The CARE Team is a multidisciplinary group of professional staff from key areas of the Institute. Each member brings knowledge and expertise in their field, including mental health, crisis intervention, student development, staff consultation, campus security, academic support, and residential life. The CARE Team also collaborates with many other entities across campus including athletics, the Equity and Title IX Office, the Caltech Center for Inclusion & Diversity, Student Faculty Programs, International Student Programs, Career Advising and Experiential Learning, and the academic divisions.

The CARE Team connects students with resources and support. Through early identification of academic difficulties, social concerns, behavioral disruptions, and health issues, the CARE Team can partner with students to create individualized plans to help mitigate crises and promote success. The behaviors listed below, especially when more than one are present, may be signs of distress:

- Mood or behavior changes
- Changes in personal hygiene
- Social withdrawal
- Excessive absences from class or lab
- Persistent disinterest or disengagement in work
- Escalated substance use
- Talking about death, dying, or suicide
- Disruptive and/or aggressive behavior
- Threatening language or social media postings

The CARE Team will collaborate with the referring party to create a support plan, which may include outreach, academic or personal counseling, referral to campus support services, and other relevant resources.

Referrals to the CARE Team can be made at: caltechcares.caltech.edu.

CAREER ACHIEVEMENT, LEADERSHIP, AND EXPLORATION (CALE)

GENERAL INFORMATION

Career Achievement, Leadership, and Exploration (CALE) aims to support students, postdocs, and recent alumni in their pursuit of a fulfilling career, including career pathways within, or at the intersection of, science, engineering, academia, industry, and public service.

CALE offers a myriad of programs and services thoughtfully designed with the goal of meeting the career and professional development needs of Caltech students and postdocs, a group that is highly technical, often ambitious, and concurrently engaged in rigorous time-intensive academic and research programs. Importantly, CALE, in partnership with the academic divisions, has adopted a hub-and-spoke model for career services. CALE acts as the central hub, overseeing core services such as employer relations and career coaching while working closely with the academic divisions to develop and maintain joint, targeted programs. This model allows for both independent and embedded programming within the academic divisions, providing for a stronger bridge between traditional coursework and a meaningful career, whether that career be in academia, industry, or the public sector. Joint programs run by CALE and an academic division(s) are open to all Caltech students, postdocs, and recent alumni regardless of option.

CALE takes a holistic approach to student development and career education, partnering closely with faculty, student and postdoc leadership, Student Wellness Services, the Hixon Writing Center, the Caltech Alumni Association, the Caltech Center for Inclusion & Diversity, Student Faculty Programs, International Student Programs, the Office of Student Experience, the Center for Teaching, Learning, and Outreach, and the Caltech Y, in order to provide relevant and timely professional development opportunities and programming.

CAREER SERVICES AND EMPLOYER RELATIONS

CALE develops and maintains robust relationships with potential employers in areas of particular interest to Caltech students, postdocs, and recent alumni, such as science, engineering, technology, finance, consulting, and the public sector. Through on-campus and virtual recruiting programs, CALE supports employer-student engagement. CALE maintains a platform through which approved employers are able to post appropriate job and internship opportunities, view the profiles and resumes of participating students, postdocs, and alumni, and schedule information sessions and interviews. CALE hosts a diverse range of companies who send representatives to campus to talk to Caltech students and postdocs about full-time employment and internship opportunities through career fairs, information sessions, and on-campus interviews. CALE and the academic divisions, through joint programs, host employers for events such as industry days, tech talks, employer office hours,

and dinners for eight. CALE is also responsible for developing and enforcing recruiting guidelines, protecting the interests of students and postdocs, while respecting the needs of employers.

CAREER COACHING, MENTORSHIP, AND EDUCATION

CALE offers programs and services targeted at each stage of the career development cycle including career exploration, job and internship search strategies and preparation, graduate and professional school preparation and application processes, career planning, and further professional development. Students, postdocs, and recent alumni can schedule individual appointments for career coaching, document review, and mock interviews; participate in workshops focused on skill building; and attend networking events. Career and vocational interest tests can be taken on the recommendation of a career coach. CALE runs peer and alumni mentoring programs in addition to employing professional career coaches. Peer and alumni mentors provide additional perspectives and are a complementary resource available to students and postdocs.

CALE partners with the academic divisions to offer curricular education and opportunities. CALE assists with the organization and management of career related courses as well as arranging for guest speakers and supporting career related curriculum design.

CALE provides advice on applying to Ph.D., master's, and professional programs in the sciences or applied sciences, engineering, economics, medicine, public health, environmental sciences, business, law, and other fields. Workshops and individual advising are available on the graduate school admissions process, essay writing, and related topics. Students planning to apply to graduate or professional school are encouraged to plan ahead and to utilize the resources of CALE in making and implementing choices related to graduate studies.

PRE-HEALTH ADVISING

Students planning to apply to medical, dental, veterinary, or pharmaceutical graduate school have access to a wide range of advising services through CALE. Students can obtain relevant medical research experience through the Caltech summer preceptorship program, which has placements with hospitals in the LA area. The pre-health adviser is available to work with students throughout the process from their first year to graduation. CALE works closely with the academic divisions and option advisers to support availability and alignment of academic coursework with medical school requirements across multiple options.

ON-CAMPUS EMPLOYMENT AND WORK-STUDY

On-campus employers including those within the academic divisions are encouraged to make use of CALE's job platform in order to advertise and recruit student employees. (See also Student Employment)

CALTECH ALUMNI ASSOCIATION

The Caltech Alumni Association (CAA) exists to ensure the personal, professional, and intellectual success and well-being of the more than 26,000 Caltech alumni around the world. Caltech Alumni advance humanity through active participation in Caltech and in the communities where they live, work, and play. Together, CAA and Techers champion education, science, and technology, using their skills, experiences, training, and education for the benefit of their communities and the world. Among CAA's programs and services are Alumni Weekend and Reunions, Seminar Day, Tables for Techers, Techer Alumni Tours, Distinguished Alumni Awards, Chang Prize, the Alumni Portal, and more. CAA publishes *Techer* alumni magazine as well as news and feature content at alumni.caltech.edu.

INTERNATIONAL STUDENT PROGRAMS

As the definitive immigration resource for international students, International Student Programs (ISP) is responsible for advising students on all immigration-related matters, such as visa acquisition, employment authorization, extensions of stay, and more. In addition, ISP provides programs that assist international students and their dependents in adjusting to life in the United States. ISP plans and promotes events that celebrate international education and cultures of the world, address cross-cultural adjustment, and provide opportunities for international students to establish a sense of community at Caltech. Prior to the fall term, ISP hosts International Student Orientation to provide an introduction to academic and social life at Caltech and in the United States. All incoming international students are required to participate. Please contact ISP at isp@caltech.edu for more information on current programs, or visit ISP online at international.caltech.edu.

AUDITING COURSES

Persons affiliated with the Institute may audit courses if they obtain the consent of the instructor in charge of the course, and the dean of undergraduate students or dean of graduate studies, as appropriate, and pay the required fee (contact the Bursar's Office for audit fee). The fees are nonrefundable.

Auditing forms may be obtained in the Registrar's Office.

Regularly enrolled students and members of the faculty are not charged for auditing. Auditing forms are not required, but the instructor's consent is necessary in all cases. No grades for auditors are reported to the Registrar's Office, and no official record is kept of the work done.

GRADES AND GRADING

GRADES AND GRADING

All permanent grades recorded for first-year students in Core classes during the first and second terms they are enrolled will be either P, indicating “passed,” or F, indicating “failed.” The temporary grade of I (“incomplete”) may be used as it is for other students. The temporary grade of E may be given to first-year students as described below for other students. It may also be used in a continuing course if the performance of the first-year student concerned is not significantly below the current passing level, and if the student is maintaining a steady and substantial improvement; an E given for this reason will be automatically changed to an appropriate grade if the first-year student earns the grade for the following term, and will change to an F if the student receives an F for the following term. The grade may not be used in this way for two successive terms nor for the last term of the course.

If a first-quarter or second-quarter First-Year student is enrolled in a course from the list of introductory courses below and the instructor for that course gives letter grades, then the registrar will record P for all passing grades. No grades given to a First-Year student for such a class during the first and second quarter in which they are enrolled will be used in computing the cumulative grade-point average. Computation of grade-point averages begins at the end of the third term of the first year; the cumulative grade-point average will include any letters grades received for non-Core non-introductory classes taken for letter grades during the first two terms of the first year.

The list of introductory courses to which this policy applies is:

- Bi 8
- Ma 2
- Ma 3
- Ph 2ab
- Ph 12ab
- Ch 41ab

Classes that are not part of the Core curriculum or the list of introductory classes above, even if taken in the first two quarters of the first year, can only count towards fulfilling graduation requirements if their grading scheme meets the requirement of the particular option.

For example suppose a student wants to fulfill their graduation requirements for the Computer Science (CS) option. In that case, they cannot take a CS course that is not part of the Core curriculum as pass/fail and use it to meet the requirements for the option. This is because the CS option prohibits pass/fail grading schemes for fulfilling its requirements. As a result, the student must take the CS course for a grade if they wish to fulfill the CS option requirement.

First-quarter and second-quarter First-Year students receive pass/fail grades in all Core and introductory courses listed by virtue of their classification as First-Year students by an admissions committee

or, for students whose status after the first year is uncertain, by the Undergraduate Academic Standards and Honors Committee.

For all students beyond the first and second quarters of their first year (as a first-year student), graduate and undergraduate, letter grades will ordinarily be used to indicate the character of the student's work: A, excellent; B, good; C, satisfactory; D, poor; E, conditional; F, failed; I, incomplete. P may also be used as described below under Pass/Fail Grading. In addition, grades of A+ and A–, B+ and B–, C+ and C–, and D+ may be used. In any situation in which no grade is reported, the grade shall be assumed to be F.

Failed

Means that no credit will be recorded for the course. The units, however, count in computing the student's grade-point average, unless the course was taken on a pass/fail basis. The student may register to repeat the subject in a subsequent term and receive credit without regard to the previous grade, the new grade and units being counted as for any other course, but the original F and units for the course remain on the record. Grades other than E, I, and W are assumed to be based on work completed and evaluated at the time of grade submission.

E AND I GRADES

E Grades

Students who are unable to complete their coursework by the end of the term may request a grade of E using the *E Grade Request Form*. Approval of the request is at the instructor's discretion. The E grade indicates that there is incomplete work that may be completed without repeating the course.

Unless the form specifies an earlier deadline, students receiving an E grade must complete their work by Add Day of the following term. If the E grade affects a student's academic standing or eligibility, the final grade may be required by the first day of classes. See the *Scholastic Requirements* section for more information.

If the required work is not completed in time for the instructor to submit a final grade by the specified deadline (either that listed by the form or Add Day), the E grade will convert to an F. Students must allow sufficient time for instructors to assess the work and submit a final grade. It is the student's responsibility to confirm that both the E grade and the final grade are properly recorded by the registrar.

With written permission from the instructor, an E grade may be extended beyond Add Day of the following term. Each extension requires a new E grade to be recorded, and a new deadline must be specified by the instructor.

E Grade Limitations

Undergraduate students may receive a maximum of six E grades during their time at Caltech. Additional E grades require a petition to the Undergraduate Academic Standards and Honors (UASH) Committee, supported by the instructor and a dean, and will be granted only in exceptional circumstances.

I Grades

The grade I (Incomplete) is granted only in cases of unexpected illness

or emergency occurring near the end of the term, preventing completion of course requirements. It is not intended to allow students to make up work missed earlier in the term. Students who have not completed the majority of the coursework are ineligible for an I grade and may be advised to late drop the course or take a leave.

An I grade is given at the discretion of the instructor, with approval from the appropriate dean. Students requesting an I grade due to the onset or exacerbation of a disability should contact Caltech Accessibility Services for Students (CASS) at cass@caltech.edu.

Unless otherwise specified by the instructor and dean, students must complete the work by Add Day of the following term. If the I grade affects a student's academic standing or eligibility, the final grade may be required by the first day of classes. See the *Scholastic Requirements* section for more information.

General Policies for E and I Grades

Students receiving an E or I grade should consult with their instructor and a dean at the time the grade is issued to clarify expectations and deadlines. In most cases, the deadline should align with Add Day of the following term unless otherwise stated.

E and I grades may not be extended beyond one year from the date they were originally assigned, except under extraordinary circumstances. After one year:

- An unresolved E will convert to an F.
- An unresolved I will convert to a W (Withdrawn).

For undergraduates, exceptions to the one-year limit require advance approval from the Dean of Undergraduate Studies, the chair of UASH, and the executive officer of the department offering the course. For graduate students, such exceptions require approval from the Dean of Graduate Studies in consultation with the Graduate Studies Committee.

Grades of E and I do not factor into a student's grade-point average.

PETITIONS AND EXCEPTIONS

Once recorded, a grade will only be changed on the basis of error. For undergraduates, a change may be made only with the approval of the Undergraduate Academic Standards and Honors Committee. For graduate students, a change may be made only with the approval of the Dean of Graduate Studies, in consultation with the Graduate Studies Committee as appropriate.

Petitions by undergraduate students for late drops (i.e., requests to drop a course after Drop Day) will be considered by the UASH Committee, but will only be approved if circumstances beyond the student's control prevented them from dropping a course or courses by the posted deadline. Such petitions must be submitted before the end of the term following the term when the course was taken, or within the first term of return, if the student is on leave in the term following the term when the course was taken. If approved, a W will be recorded on the student's transcript in place of a grade for that

course. W's will not be included in the computation of the student's grade-point average. Courses will be expunged from the student's record only in exceptional circumstances, at the discretion of the UASH Committee.

Petitions from graduating seniors submitted later than the first UASH meeting following graduation (which normally takes place shortly after graduation) will not be accepted for consideration, except to correct an error by the Institute.

GRADE-POINT AVERAGE

Grade-point average is computed by dividing the total number of credits earned in a term or an academic year by the total number of units taken in the corresponding period. Units for which a grade of F has been received are counted, even though the course may have subsequently been repeated. Grades of P or F obtained in courses graded on a pass/fail basis are not included in computing grade-point average.

Each course at the Institute is assigned a number of units corresponding to the total number of hours per week devoted to that subject, including classwork, laboratory, and the normal outside preparation. Credits are awarded as shown in the table below.

No. of Units	A+	A	A–	B+	B	B–	C+	C	C–	D+	D	F
1	4	4	4	3	3	3	2	2	2	1	1	0
2	9	8	7	7	6	5	5	4	3	3	2	0
3	13	12	11	10	9	8	7	6	5	4	3	0
4	17	16	15	13	12	11	9	8	7	5	4	0
5	22	20	18	17	15	13	12	10	8	7	5	0
6	26	24	22	20	18	16	14	12	10	8	6	0
7	30	28	26	23	21	19	16	14	12	9	7	0
8	35	32	29	27	24	21	19	16	13	11	8	0
9	39	36	33	30	27	24	21	18	15	12	9	0
10	43	40	37	33	30	27	23	20	17	13	10	0
11	48	44	40	37	33	29	26	22	18	15	11	0
12	52	48	44	40	36	32	28	24	20	16	12	0
13	56	52	48	43	39	35	30	26	22	17	13	0
14	61	56	51	47	42	37	33	28	23	19	14	0
15	65	60	55	50	45	40	35	30	25	20	15	0

PASS/FAIL GRADING

Pass/Fail Grading, the following regulations apply

- First-quarter and second-quarter First-Year students receive pass/fail grades in all Core and introductory courses listed by virtue of their classification as First-Year students by an admissions committee or, for students whose status after the first year is uncertain, by the Undergraduate Academic Standards and Honors Committee.
- All other students, undergraduate and graduate, in courses with numbers under 200 will receive letter grades unless the course is designated "graded pass/fail'' or unless, when it is allowed, the student submits a change to the course's grading scheme on or before Drop Day.
- In courses with numbers 200 or greater that are not designated either "graded pass/fail'' or "letter grades only,'' the instructor may decide separately for each student what class of grades to use.
- All research courses shall be designated "graded pass/fail.'' All reading courses, seminar courses, or other courses that do not have a formal class structure shall be designated "graded pass/fail'' unless the option secures an exemption from the Curriculum Committee or the Graduate Studies Committee and from the Faculty Board.
- A grade on the pass/fail system should be P if it would have been a D or better on the letter grade system. (Note that there is no D– grade.) The standards of failure in courses in which only pass/fail grades are used should be the same as they would be if the course were letter graded.
- Any instructor may, at their discretion, specify prior to registration that their course, if not classified by the above regulations, is to be graded on a "letter grades only'' basis or is to be graded pass/fail only, subject to possible review by the responsible option. The registrar must be notified of such specification two weeks before the beginning of registration. (Note: A course's grading scheme is not changed after it has begun.)
- Each term, any student may select, subject to requirements imposed by the student's option, two elective courses in which they are to be graded on a pass/fail basis if the course is not designated as "letter grades only'' and is not specifically required for the degree in their option. To make this election, a student must submit a change to the course's grading scheme in REGIS, or submit a written request to the Registrar's Office, on or before Drop Day. This election may be reversed or reinstated at any time before the deadline. Students must resubmit their schedule in REGIS after all changes, and the pass/fail election must be approved by the student's adviser. The instructor must allow any eligible student to make this election.
- Of the units offered to satisfy the requirements for the Bachelor of Science degree, no more than 90 may be in courses graded

pass/fail because of the student's election (this does not include those courses taken in the first two terms during an undergraduate's first year (as a first-year student) or those designated pass/fail by the instructor, option, or curriculum committee).

PROCEDURES FOR RESOLVING DISPUTES OVER GRADING

At Caltech, the instructor has full responsibility for assigning grades to students enrolled in a course. On occasion, a student may not understand how a grade was determined and may seek further information. The student should first meet with the instructor or teaching assistant to discuss the grade. If after doing so the student believes the grade is unjustified or capricious, the following procedures are available.

Before the end of the term following the term when the grade was issued, the student should contact the academic mediator, appointed by the provost, who will work with the student and instructor to resolve the problem. If the mediation effort is unsatisfactory to the student, they may request a formal review by an appropriate executive officer or academic officer. The executive officer will review the case and report the decision in writing to the student. If the executive officer decides that a change of grade is warranted, or if the student requests a further appeal, these shall be requested of the division chair. At the discretion of the division chair, a committee may be appointed to review the case. The committee members should interview everyone involved in the case (the student, the course instructor, the teaching assistant, and anyone else with relevant information), and make a written recommendation to the division chair. Only the division chair can authorize the registrar to enter a new grade in the student's transcript.

NOTICES AND AGREEMENTS

ACADEMIC RECORDS OF VETERANS

The Institute maintains a written record of a student's previous education. This is part of the student's official transcript, and included on this is a summary of any prior college-level education. A true copy of a transcript of college-level work at other institutions is maintained as part of the student's record. The amount of credit granted for prior training is indicated on the student's official transcript and, where this results in the shortening of a required training period in the case of a veteran, the Veterans Administration is notified.

The Institute's official transcript for each student shows the progress that student is making at the Institute. There is a record of each course enrolled in each term with a grade recorded for the course. The total number of units earned is kept so that the record will show continued progress toward the degree sought. The final grades are recorded at the end of each term of the school year, and the accumulative permanent record has on it grades for all subjects taken

at the Institute. No student is allowed to enroll repeatedly in a course and withdraw without penalty. If a student enrolls in a course, they are expected to complete the course or receive a failing grade unless they withdraw from the course prior to the deadline for dropping courses. All students must maintain a minimum load equivalent to 12 quarter hours each term; no student may drop courses that would bring them below this level of effort. At any time when the student falls below the required number of units, fails to receive satisfactory grades, or engages in unsatisfactory conduct, the record is marked to indicate this, and the student is forbidden to continue at the Institute.

The grading system of the Institute is A+ (excellent) to F (failed). An A+ is equivalent to 4.3 and an F to 0.0. A student must maintain a grade-point average of 1.9 in any term in order to be able to enroll in a successive term at the Institute. A minimum 1.9 overall grade-point average is required for graduation. A student who drops below the required average (1.9 for a given term) is dismissed and must petition for reinstatement. A student may be reinstated by the Undergraduate Academic Standards and Honors Committee and, if so, is required to earn a 1.9 GPA during the immediately following term. The Veterans Administration is notified when a veteran is academically dismissed or is making unsatisfactory progress toward a degree. Since the Institute requires all students to carry a minimum full load that corresponds to 12 quarter hours each term, any student who finishes a term in good standing is considered to have made satisfactory progress. If a student withdraws from a course before the final date for withdrawal, no grade is given in that course. The time spent in school counts, however, and the student may be considered to have not made satisfactory progress in the event of such withdrawal.

In order to withdraw from any course, a student must drop the course in REGIS or submit a written request to the Registrar's Office. The instructor should maintain the date on which the student was last in official attendance in that course. If a student reenrolls in that course and successfully completes it, that fact will be noted on their official transcript.

Veterans Benefits and Transition Act of 2018 (Section 103)
Caltech adheres to the requirements of and complies with the Veterans Benefits and Transition Act of 2018, specifically S2248 PL 115-407 Section 103. This provision was effective August 1, 2019 for any students who are considered "a covered individual" using "Chapter 33: Post 9/11 GI Bill®" benefits or any participants in "Chapter 31: Vocational Rehabilitation and Employment Program" benefits at a public, private for-profit, or not-for-profit institution regarding unpaid tuition and fees.

Caltech permits any covered individual to attend or participate in courses during the period beginning on the date on which the individual provides to the educational institution a certificate of eligibility for entitlement to educational assistance under chapter 31 or 33 of this title.

In accordance with S2248 PL 115-407 Section 103 Caltech will not impose any penalty, including the assessment of late fees, the denial

of access to classes, libraries, or other Institute facilities, or the requirement that a covered individual borrow additional funds, on any covered individual because of the individual's inability to meet their financial obligations to the institution due to the delayed disbursement of a payment to be provided by the Secretary under chapter 31 or 33 of this title.

GI Bill® is a registered trademark of the U.S. Department of Veterans Affairs (VA). More information about education benefits offered by VA is available at the official U.S. government Web site at www.benefits.va.gov/gibill.

ACCESS TO STUDENT RECORDS

The Institute maintains educational records for each student that include name, address, student identification number (including Social Security number), information on parents, guardian, and spouse, general information on academic status at the Institute, previous school data, results of standardized admissions examinations, courses previously taken or being taken, credits, grades, as well as other educational records. Applicants for financial aid have an additional file holding those records. The Family Education Rights and Privacy Act (FERPA) and Caltech policy afford students certain rights as well as establish limitations with respect to student educational records. These rights and limitations are as follows:

1. Caltech permits disclosure of educational records, without consent of the student, to Institute officials with legitimate educational interests in them. An Institute official is a person employed by the Institute in an administrative, supervisory, academic or research, or support-staff position (including security personnel and health and diversity center staff), a person or company with whom the Institute has contracted (such as an attorney, auditor, consultants, contractors, or collection agent), a person serving on the Board of Trustees, or a student serving on an official committee, such as a disciplinary or grievance committee, or assisting another Institute official in performing their tasks. An Institute official has a legitimate educational interest if they need to review an educational record in order to fulfill their professional responsibility. They are available to the registrar, provost, president, general counsel, vice president for development and institute relations, vice president for student affairs, dean of graduate studies, dean of undergraduate students, director of financial aid, and faculty of the Institute and their respective staffs for the normal academic and business purposes of the Institute. Records involving financial aid are maintained by the director of financial aid, and are available to the director and staff, to the dean of graduate studies and staff, to the Faculty Committee on Scholarships and Financial Aid, and to the Faculty Committee on Graduate Study, for the purpose of granting and administering the Institute's financial aid program. Except as authorized by federal or state law or regulation, none of these education records nor any personally-identifiable information contained therein, other than directory information (see below), may be made available to anyone else, other than the student, without the consent of the student. Where the student consents to

disclosure of personally-identifiable information from the student's education records and Caltech chooses to disclose such information, if the student so requests, the Institute will provide the student with a copy of the records disclosed. The Institute will maintain a record of each request for access to and each disclosure of personally-identifiable information from the education records of a student, as required by applicable federal law or regulation.

2. Students are allowed access to their educational records as follows: A student may inspect and review their academic transcript during normal working hours. To inspect and review other records, the student must provide a written request to the registrar or to the director of financial aid or to the dean of graduate studies or to the dean of undergraduate students, or their designees, as appropriate. A mutually-convenient time will be arranged within 45 days after receipt of the request for the student to inspect and review the records in their file. At that time the student may examine all educational records in the file with the exception of those specifically exempted by Part 99 of Title 34 of the Code of Federal Regulations. If circumstances effectively prevent the student from exercising their right to review their education records, the Institute will make other arrangements. If a student believes the educational records relating to the student contain information that is inaccurate, misleading, or in violation of the student's rights of privacy, the student may ask the Institute to amend the record. The Institute will decide whether to amend the records as requested within a reasonable time after receiving the request. If the registrar, or the director of financial aid, or the dean of graduate studies, or the dean of undergraduate students, or their designees, decide not to amend the record as requested, the student will be informed of the decision and of their right to a hearing. The student will have, on request, an opportunity for a hearing to challenge the content of the records on the grounds that the information contained in the records is inaccurate, misleading or in violation of the privacy rights of the student. To request a hearing, the student must submit a written request to the vice president for student affairs or their designee. The vice president for student affairs or their designee will schedule such a hearing within a reasonable time after receipt of the request and will notify the student at a time reasonably in advance of the hearing of its date, time, and place. The student will be afforded a full and fair opportunity to present evidence relevant to the issues raised and may be assisted or represented by individuals of their choice at their own expense, including an attorney. The decision of the vice president or designee will be in writing, will be rendered within a reasonable time after the conclusion of the hearing, and will be final. This decision will be based solely upon the evidence presented at the hearing and will include a summary of the evidence and of the reasons for the decision. If, as a result of the hearing, the Institute decides that the information is inaccurate, misleading, or otherwise in violation of the privacy rights of the student, the Institute will amend the record accordingly, and inform the student of the amendment in writing. However, if, as a result of the hearing, the Institute decides that the information is not inaccurate, misleading, or otherwise in violation of the privacy rights of

a student, it will inform the student of the right to place in the educational records a statement commenting on the information in the records and/or setting forth any reasons for disagreeing with the decision of the Institute. If the Institute places a statement in the education records of the student, the Institute will maintain the statement with the contested part of the record for as long as the record is maintained and will disclose the statement whenever it discloses the portion of the record to which the statement relates.

3. The Institute considers the following to be directory information: a student's name, UID, addresses (permanent, campus and local/off-campus, and email), associated telephone listings, ID photograph, date and place of birth, major field of study, year in school, current enrollment status, expected date of graduation, name of academic adviser, participation in officially recognized activities and sports, weight and height if a member of an athletic team, dates of attendance, degrees and awards received, thesis title, hometown, and most recently attended educational agency or institution. Directory information may be made available to requestors at the Institute's discretion. Any student may, however, have part or all of this information withheld by notifying the registrar in writing. That information will then be withheld for the balance of that academic year. If the information is to be withheld in subsequent years, new requests must be filed.

4. A student will not be required to waive any rights regarding access to educational records. However, a student may voluntarily waive in writing right of access to confidential statements made by third parties respecting admission to educational agencies or institutions, applications for employment, or the receipt of an honor or honorary recognition. In case of waiver, the confidential statements will be used solely for the purposes for which they were specifically intended, and the student will, upon request, be notified of the names of all persons making such confidential statements. If a student should desire to waive right of access, may contact the registrar for more information.

5. The Institute reserves the right to destroy from time to time any and all educational records that it maintains on a student, except to the extent that the law requires their maintenance for a longer period of time. However, where access to records has been requested, no destruction of those records will be allowed to take place until such access has been granted or denied.

6. Students who believe their rights under FERPA may have been violated may file a complaint with the Family Policy Compliance Office, U.S. Department of Education, 400 Maryland Avenue SW, Washington D.C. 20202-4605.

Transcripts of Records

A student, or former student, may request that official transcripts of their records be forwarded to designated institutions or individuals. Requests should be filed at the Registrar's Office at least five days before the date on which the transcripts are to be mailed.

PARENT, GUARDIAN, AND EMERGENCY CONTACT NOTIFICATION POLICY

Caltech understands and supports a student's right to confidentiality regarding educational records1 as well as matters related to a student's experience at the Institute. Most communications from Caltech regarding academics, health and safety, advising, enrollment, and policies are directed only to students. However, the Institute does encourage students to share important information with their parent(s) or guardian. Subject to the allowable exceptions under FERPA, there may be circumstances under which a Caltech administrator makes the determination that notification to parent(s) or a guardian is indicated, and notification may be made without a student's consent. In most cases, when a Caltech administrator determines that involving parent(s) or guardian is necessary, the student will be given an opportunity to make contact in advance of the administrator's communication. Administrators will consider any relevant information which may indicate that notification to parent(s) or guardian may not be appropriate based on individual circumstances. The Institute expects all students to designate an emergency contact who is a parent or guardian or other family member who may be notified in order to address a health or safety emergency, and who is in a position to make decisions on the student's behalf in the case of a medical emergency. An alternate emergency contact also may be identified for other purposes.

Situations that may warrant the involvement of a student's, parent(s), guardian, or emergency contact may include, but are not limited to:

1. Concerns about a student under the age of 18.
Caltech administrators will initiate communication with the parent(s) or guardian of a minor student in the cases described below, as well as any other concerns about a minor student that may benefit from collaboration with the student's support system.

2. Change in enrollment or status of an undergraduate student.
A change in the enrollment status of an undergraduate student may occur as a result of disciplinary action, unsatisfactory academic progress, or other factors. If an undergraduate student is separated from the Institute, the parent(s) or guardian will be notified by mail at the permanent address on file.

3. Medical emergencies.
State law prohibits health care professionals from disclosing medical information to the parents or guardian of a student without the student's explicit consent. In the event a student is incapacitated, unable to communicate, or otherwise cannot make decisions on their own behalf, the Institute will first cooperate with medical providers and then notify the emergency contact, parent(s) or guardian on file as soon as possible.

4. Unexplained absence from campus.
Caltech has established a policy to assist in locating Caltech students living in Caltech campus housing when Caltech has determined a student to be missing. The key components of this policy are as follows:

- *Designation of Confidential Contact.* Students have the option of identifying an individual to be contacted by Caltech within 24 hours after the time the student has been determined to be missing (missing person contact). This information will be accessible only to authorized campus officials and may not be disclosed except to law enforcement personnel in a missing person's investigation. If a student chooses not to provide a confidential contact and is deemed to be missing, Caltech will notify the student's emergency contact or parent.
- *Reporting and Investigation.* Any individual who believes a student living in on campus housing may be missing should immediately contact Caltech Campus Security. Once Caltech receives a missing student report, Security will notify the Vice President for Student Affairs, the Deans, the AVP for Student Affairs and Residential Experience and the Director of Housing. Upon notification that any student may be missing, Caltech will initiate an investigation. If a student is determined to have been missing for twenty-four (24) hours and has not returned to campus, Caltech will notify the appropriate law enforcement agency and initiate other notifications as provided below.
- *Notification Procedures.* A student's missing person contact will be notified within 24 hours of a determination by Caltech that the student is missing. If no missing person contact has been designated, the student's emergency contact will be notified. If the student is under 18 years of age and not an emancipated individual, Caltech is also required to notify a custodial parent or guardian within 24 hours of the determination that the student is missing.

5. Significant disruption to the campus community.
The emergency contact, parent(s) or guardian of a student may be notified if the student is behaving in a way that is substantially disruptive to the campus community, there is reason to believe the student is at risk of harming themselves or others, or is placed under arrest or charged with a crime related to conduct on campus.

6. Repeated or flagrant violations of the Substance Abuse Policy.
Caltech administrators may contact parent(s) or guardian if a student under the age of 21 is found responsible for serious or repeated violations of Institute policy related to the possession, use or distribution of alcohol or drugs. Consideration in these situations will be given to the following conditions: the violation involved harm or threat of harm to self, others or property; the violation involved an arrest in which the student was taken into custody; the violation resulted in or could result in the student being suspended and/or

removed from an Institute residence; the student has shown a pattern of violations; the student required urgent medical intervention as a result of consumption of alcohol and/or drugs.

7. Student death.
In the event of a student death, Caltech administrators will cooperate with law enforcement, the coroner, medical personnel, and any other relevant officials who will provide official notification to the deceased student's next of kin.

There may be additional, unforeseen circumstances when we believe it is in the best interest of the student to notify a parent or guardian. We reserve the right to act in such cases on our own best judgment, framed within the approach to emergency contact and parental/guardian notification stated above.

[1]*The Family Educational Rights and Privacy Act (FERPA) (20 U.S.C. § 1232g; 34 CFR Part 99)*

ACCREDITATIONS AND AUTHORIZATIONS

The California Institute of Technology is accredited by the WASC Senior College and University Commission (WSCUC), 985 Atlantic Ave., Ste. 100, Alameda, CA 94501; (510) 748-9001. In addition, the Institute is authorized by the California State Department of Education, Office of Private Postsecondary Education, to operate as a private postsecondary educational institution and, by the same agency, to train veterans in the programs of the Veterans Administration.

The Engineering Accreditation Commission of ABET, Inc. (111 Market Place, Suite 1050, Baltimore, MD 21202-4012; 410-347-7700), has accredited Caltech's B.S. program in mechanical engineering. Further, the Committee on Professional Training of the American Chemical Society has approved Caltech's B.S. program in chemistry.

The documents describing these accreditations and authorizations are on file and may be inspected in the Registrar's Office and the Provost's Office; the office of the Division of Engineering and Applied Science also has the documentation for ABET.

STUDENT PROBLEM RESOLUTION PROCESS

Caltech provides a variety of routes, most of them informal, by which students may bring complaints, which do not fall within the jurisdiction of other Policies or the Honor System, for consideration and resolution. For example, in academic matters, students may begin with faculty-student conversations that may extend to the deans, the option representatives, the division chairs, the registrar, or to various committees having faculty and student members. Non-academic matters can be dealt with informally by student leaders, resident associates, residential life coordinators, deans, and other student affairs offices. The Graduate Student Council (GSC) and the Associated Students of the California Institute of Technology (ASCIT) may become involved in some complaints, and sometimes ad hoc groups are formed to make recommendations.

The Problem-Resolution Process (Process) is intended to deal with complaints by currently enrolled students for which reasonable efforts

by the available informal routes have not led to an acceptable resolution.

The first step in this Process is for the student to consult with the appropriate deans. One of the deans will then determine if the issue falls under this Process and, if appropriate, may appoint a facilitator to help resolve the issue. If the student's issue involves a decision or action of a dean, the vice president for student affairs or designee may appoint a facilitator to help resolve the issue.

A facilitator will assist the student in trying to work out the problem. If the student is not satisfied with the results, the student may file a written notice of appeal to the vice president for student affairs or their designee. The decision of the vice president or designee is final.

If a student has a complaint about Caltech's compliance with academic program quality and accrediting standards that they believe warrants further attention after exhausting the steps outlined above, they may contact the WASC Senior College and University Commission (WSCUC) at www.wscuc.org/comments. WASC is the academic accrediting body for Caltech. An individual may contact the Bureau for Private Postsecondary Education (BPPE) for review of a complaint. BPPE may be contacted at 2535 Capitol Oaks Drive, Suite 400, Sacramento, CA 95833, website: www.bppe.ca.gov; telephone: (916) 431-6959; fax: (916) 263-1897. Prospective students may contact WASC or the BPPE with complaints as well.

STUDENT PATENT AND COMPUTER SOFTWARE AGREEMENT

The California Institute of Technology (Caltech) has a responsibility to see that inventions and copyrightable materials (including software) developed in connection with Caltech be used for the public benefit, and be consistent with Caltech's contractual obligations. In view of the patent and copyright policies of Caltech in force on this date and as may from time to time be amended, and my use of and access to Caltech facilities and equipment, I agree to the following:

Caltech retains all rights in inventions and computer software I generate as a student at the Caltech campus, Jet Propulsion Laboratory (JPL), and other facilities owned or managed by Caltech, with the following exceptions:

1. When I generate copyrightable computer software or other written work at Caltech in connection with my enrollment in Caltech's educational program, such as in course work, homework, theses and publications, I understand that I will retain ownership of copyrights to these works, and I hereby grant to Caltech an irrevocable royalty-free nonexclusive license to use such computer software and written work for educational and research purposes, including the right to grant sublicenses. If the work is generated at JPL or any Caltech owned or managed facility, I also hereby grant to the United States Government ("Government") a royalty-free, nonexclusive license to use such computer software and written work for purposes for or on behalf of the Government, to the extent Caltech or the Government requires such a license.

2. When I make inventions, write computer software or other written work entirely on my own time, without using Caltech's equipment or facilities (other than incidental use of electronic information resources as is permitted under Caltech policy), and without using Caltech funds, I retain ownership of those inventions, software and written work.

I agree to assign, and hereby do assign, to Caltech all inventions and copyrightable materials that I develop with the use of funds administered by Caltech, or in the course of my duties at or for Caltech, including JPL, or with use of other facilities owned or managed by Caltech, apart from those for which I retain rights under numbered paragraphs 1 and 2 of this agreement, and all copyrights, patent applications and patents relating to those inventions and copyrightable materials.

I agree to execute all papers required to apply for, obtain, maintain, issue and enforce the assigned copyright registrations, patents and applications; and to provide reasonable assistance regarding those copyrights, patents and patent applications, including testifying in any related patent office proceeding, dispute or litigation. Expenses for the copyrights and patent applications, and for the assistance set forth in the preceding sentence, shall be borne entirely by Caltech.

I agree to notify Caltech promptly of all such assigned inventions or copyrightable materials.

I understand that if Caltech receives funds from the licensing of the assigned copyrightable materials or patents in excess of unreimbursed expenses associated with obtaining, maintaining and enforcing those copyrights and patents, I will share in these funds according to the established Caltech policy, procedures and practice in effect on the date that the patent application is filed or the computer software is completed, in the same manner as a member of the academic staff and employees.

I agree to notify Caltech of any funding of which I am aware that may have supported an assigned invention described in the preceding paragraphs. This is to ensure Caltech's compliance with its obligations, including the provisions of the Federal Bayh-Dole Act and implementing regulations. For work done at JPL, I agree to have all scientific and technical publications reviewed, pursuant to JPL policy, prior to public release to ensure compliance with U.S. export control laws.

I understand that Caltech relies on this agreement when it enters into contracts with others and obligates itself with respect to inventions and computer software developed at Caltech.

Revised 03-23-2015

STUDENT RETENTION AND PERSISTENCE RATES

Most undergraduates enter Caltech at the first-year level. Of the 225 first-year students enrolled during the 2020-21 academic year, 223 reenrolled in the first term of the 2021-22 academic year and are progressing, yielding a persistence rate* of 99 percent after all allowable exclusions. Of the 241 first-year students enrolled during the 2014-15 academic year, 223 graduated by June 2021, yielding a graduation rate for this group of 93 percent after allowable exclusions.

At the graduate level, most students enter Caltech to pursue either the degree of Master of Science or Doctor of Philosophy or, occasionally, both. Of the 238 entering graduate students enrolled in a Ph.D. program during the 2020-21 academic year, 229 reenrolled in the first term of the 2020-21 academic year and are making satisfactory academic progress, resulting in a persistence rate* of 96 percent. Of the 7 entering graduate students enrolled in M.S. programs during the 2020-21 academic year, 2 earned a terminal M.S. degree within one year and one completed the M.S. degree and continued in the Ph.D. program.

STUDENT EVENTS

Caltech is committed to providing its students, faculty and staff with an environment that promotes safe and responsible social interaction. Caltech recognizes that student activities are an important part of campus life. Students are required to follow Event Planning Procedures: spa.caltech.edu.

STUDENT VACCINATION POLICY

Immunization against life-threatening diseases is an important tool in the prevention and mitigation of infectious disease outbreaks. This vaccine policy may be modified in response to changes in public health requirements or recommendations. To protect the health of both students and the community as a whole, Caltech has required the following vaccines (or serologic proof indicating immunity, when applicable) for all enrolled students:

- **Measles, Mumps, and Rubella (MMR):** Two doses of measles, mumps, and rubella (MMR) vaccine **OR** blood test showing immunity (positive titers).
- **Varicella (Chicken Pox):** Two doses of varicella (chicken pox) vaccine **OR** blood test showing immunity (positive titer).
- **Tetanus, Diphtheria, and Pertussis (Tdap):** One dose of tetanus, diphtheria, and pertussis (Tdap) given after age 7. Afterward, a booster dose of tetanus and diphtheria (Td) every ten years.
- **Meningococcal Conjugate ACWY (Meningitis):** One dose of meningococcal conjugate ACWY (meningitis) after age 16 for all students under age 22.

Recommended Vaccinations:

- Annual Influenza (Flu) for all students
- COVID-19 vaccination for all students
- Hepatitis A for all students
- Hepatitis B for all students
- Human Papillomavirus (HPV) for all students
- Poliovirus (Polio) for all students
- Haemophilus influenza for certain students
- Jynneos (M-Pox) vaccine for certain students
- Meningitis B for certain students
- Pneumococcal for certain students

- Zooster vaccination for age 50 years or older

See wellness.caltech.edu policies for updates.

PARENT, GUARDIAN, AND EMERGENCY CONTACT NOTIFICATION POLICY

Caltech understands and supports a student's right to confidentiality regarding educational records1 as well as matters related to a student's experience at the Institute. Most communications from Caltech regarding academics, health and safety, advising, enrollment, and policies are directed only to students. However, the Institute does encourage students to share important information with their parent(s) or guardian. Subject to the allowable exceptions under FERPA, there may be circumstances under which a Caltech administrator makes the determination that notification to parent(s) or a guardian is indicated, and notification may be made without a student's consent. In most cases, when a Caltech administrator determines that involving parent(s) or guardian is necessary, the student will be given an opportunity to make contact in advance of the administrator's communication. Administrators will consider any relevant information which may indicate that notification to parent(s) or guardian may not be appropriate based on individual circumstances. The Institute expects all students to designate an emergency contact who is a parent or guardian or other family member who may be notified in order to address a health or safety emergency, and who is in a position to make decisions on the student's behalf in the case of a medical emergency. An alternate emergency contact also may be identified for other purposes. A missing emergency contact may result in a hold being placed on a student's account.

CODE OF CONDUCT

THE CALTECH COMMUNITY'S STATEMENT ON ETHICAL CONDUCT

We are all part of the Caltech community whether we are located on campus, at JPL, at observatories or anywhere else in the universe. As members of the Caltech community, we expect that each of us will embody the high standards that have gained Caltech its worldwide reputation. In 2012, members representing the Caltech community began a conversation on ethical conduct. These discussions focused on the overarching values of our community. As a result of these discussions, we describe, in detail, these values in 11 short statements.

1. Strive for Excellence

- We commit to excellence in all things in process as well as outcomes, knowing that only the process is truly under our control.
- Responsibility and accountability are the hallmarks of our
- community.

2. Act with Integrity

- We uphold integrity in all we do.
- We hold ourselves accountable for the outcomes of our actions.

3. Encourage Open, Honest, and Respectful Discourse

- We encourage open, honest, and respectful discourse from and between all members of the community, regardless of position, length of service, or role.
- We treat one another with civility.

4. Respect and Promote Freedom of Inquiry

- We encourage curiosity in research, scholarship, and exploration, and we create the conditions where inquiry can flourish.

5. Foster a Supportive and Diverse Community

- Every member of the Caltech community treats one another with dignity and respect.
- We value different perspectives, opinions, and ideas.
- We enable one another's excellence.
- We support the health and wellness of all community members.

6. Commit to Education

- The opportunity for excellence in education exists at all levels and in formal and informal ways that benefit students, employees, and members of our community.
- We are committed to being great educators—as leaders, mentors, and friends—not only of our students, but also of our community, our peers and colleagues, and ourselves.

7. Conduct Work Responsibly

- We fulfill the obligations of our role.
- We are responsible stewards of the Institute resources entrusted to us, including the environment, equipment and facilities, money and people.
- We respect the environment and are conscious of our impact.

8. Protect the Interests of Those Who Place Their Trust in Us

- We are forthright with our students, their parents, employees, managers, and people who rely on us for leadership and accountability at all levels.
- We hold ourselves to the highest standards of integrity in peer reviews, scientific evaluations, and recommendations.
- We represent ourselves accurately and factually to our peers, sponsors, and the general public.

- We are open and honest in all our dealings with the government, external agencies, taxpayers, and donors.
- We honor our obligations to donors and sponsors.

9. Provide and Maintain a Safe Environment for Learning and Working

- We create, provide, and maintain a safe environment for ourselves and for others.
- We foster the physical, mental, and emotional well-being of our community.

10. Obey the Law and Comply with Institutional Policies

- We are scrupulous in all business dealings.
- We are truthful, forthright and accurate when preparing all books, records, documents, reports, and publications.
- We adhere to local, state, and federal laws and regulations.
- We deal honestly with government in all matters.

11. Represent Caltech

- We represent Caltech whether we are based on campus, at JPL, our observatories, or anywhere else in the world.
- We are ambassadors and advocates, embodying the high standards that we set for ourselves and to which we are held by others.
- We are committed to the Institute and its mission recognizing that our actions as individuals reflect on Caltech.

As members of the Caltech community, we embrace the letter and the spirit of these principles. Each member is personally responsible for incorporating these principles into their own actions and is encouraged to speak up if they, in good faith, believe the Institute or any individual is falling short of living up to them. We are proud of Caltech and to share the community's commitment to these values.

INSTITUTE POLICIES

ACCEPTABLE USE OF ELECTRONIC INFORMATION AND COMPUTING RESOURCES

Caltech provides electronic information and computing resources (including, but not limited to, computers, computer accounts and services, networks, software, electronic mail services, electronic collaboration and communication platforms, electronic information sources, video and voice services, servers, websites, mobile devices, and related services) to assist members of the Caltech community in the pursuit of education and research. This policy, in conjunction with other applicable Caltech policies, sets forth the acceptable use of all electronic information resources owned or managed by Caltech (including those operated by third parties for Caltech, such as accounts or other computing services issued by third-party services for Caltech) (collectively, "**Caltech IT resources**") and describes the

rights and responsibilities of Caltech and faculty, staff, students, postdoctoral scholars, visitors and guests and other members of the Caltech community.

Caltech IT resources are intended to be used to carry out the legitimate business of Caltech, although some reasonable incidental personal use is permitted. Incidental personal use must not violate any laws, Caltech's policies, including restrictions on political or outside commercial activities, or the safety, security, privacy, reputational, and intellectual property rights of others. Caltech is not responsible for any loss or damage incurred by an individual that results from personal use of Caltech IT resources.

Faculty, staff, students, postdoctoral scholars, visitors and guests and other members of the Caltech community ("users") who use Caltech's electronic information resources should be guided by the Caltech Code of Conduct. Passwords and other authentication mechanisms or devices issued to users are for their use only and are not to be shared with others. Users assume responsibility for the appropriate use of Caltech IT resources and agree to comply with all relevant Caltech policies and all applicable local, state, and federal laws. Examples of inappropriate or unauthorized use of Caltech IT resources include, but are not limited to:

- sending a communication or using electronic information resources, including websites, collaboration and communication platforms and social media sites to illegally discriminate against, harass, defame, or threaten individuals or organizations;
- sending communications that are threatening or that may constitute stalking under Caltech's policies regarding Violence Prevention or Sex Discrimination policies;
- engaging in illegal conduct or conduct that violates Caltech policy;
- collecting, distributing, or publishing, by means of an electronic communication device, another individual's personal identifying information or private or confidential information, for purposes that are in violation of the law, including with the intent to cause fear, injury, or harassment (commonly referred to as "doxxing");
- destruction of, damage to, or malicious tampering with equipment, software, or data belonging to Caltech or to others;
- disruption, interception, or unauthorized monitoring of electronic communications;
- interference with use of Caltech systems;
- bypassing or otherwise tampering with computer security systems;
- unauthorized use of accounts, access codes, passwords, or identification numbers;
- use that intentionally impedes the legitimate computing activities of others;
- use for commercial purposes;
- use for cryptocurrency mining or any other personal profit-generating activities;

- use for political or lobbying activity that jeopardizes Caltech's tax-exempt status and violates Caltech's Political Activities Guidelines;
- violation of third-party intellectual property rights, including rights protected under patent, trademark, and copyright laws;
- downloading, posting, or sharing copyrighted materials, or any other unauthorized use or distribution of copyrighted materials;
- violation of software license terms;
- unauthorized use of Caltech's trademarks;
- unauthorized disclosure of proprietary or confidential information;
- violations of privacy;
- academic dishonesty;
- sending social media chain mail, spam, or other junk messages;
- fraudulent activity using Caltech IT resources;
- downloading, viewing, and/or sharing of materials in violation of Caltech's policies regarding Unlawful Harassment, Discrimination, and Abusive Conduct and Sex Discrimination ;
- unauthorized intrusion into computer systems;
- unauthorized security testing or scanning of Caltech IT resources or of another entity;
- sending communications that attempt to hide the identity of the sender or represent the sender as someone else;
- altering or disabling security devices or security configurations on IT assets; or
- encrypting data or systems using cryptography that has not been reviewed and approved by Caltech; or
- use of generative AI and large language model tools in a manner that is inconsistent with Caltech's Guidance on the Use of Generative AI and Large Language Model Tools.

Caltech will apply this policy consistent with applicable requirements under the laws and regulations governing Caltech's operations. This policy will not be construed or applied in a manner that improperly interferes with employees' rights under the National Labor Relations Act.

Caltech IT resources are Caltech property or licensed by Caltech for Caltech's use. Users of Caltech IT resources should not have an expectation of privacy with respect to their use of these resources or any of the data, files, or other records generated by, stored, or maintained on them. For cybersecurity and other lawful purposes, Caltech may collect, store, and analyze information on both of the following: (1) any and all use of Caltech's electronic information resources and (2) any data or communications transmitted to or from, received or printed from, or created, stored, accessed, or recorded on Caltech's electronic information resources. This is true regardless of the labeling of the data, the use of encryption, the deletion of the data or communications, or any other factor.

Users of Caltech computing resources and information should understand the sensitivity level of the resources under their control and provide appropriate protection to both systems and data. Password capabilities and other authentication measures are provided

to users in order to safeguard electronic messages, data, files, and other records (including computer files and records, electronic mail, and voicemail) and computing equipment from unauthorized use. These safeguards are not intended to provide confidentiality from Caltech monitoring with respect to personal messages or files stored on electronic information resources owned or managed by Caltech.

While Caltech does not routinely examine the content of electronic mail or communication messages or otherwise monitor individual usage, it does routinely monitor the normal operation of computing and networking resources, including network activity patterns, system logs, general and individual usage patterns, and other indicia necessary to ensure the integrity and stability of its electronic information resources.

Caltech will investigate suspected abuse, misuse, or compromise of its resources, systems, and services. Any user found to have violated this policy may be subject to disciplinary action, up to and including loss of administrative rights or network/system access, termination of employment, student expulsion, or being permanently excluded from Caltech-controlled premises.

Caltech retains the right to inspect, review, or retain the content of electronic messages or other data, files, or records generated, stored, or maintained on Caltech IT resources at any time without prior notification. Any such action will be taken for reasons Caltech, within its discretion, deems to be legitimate. These legitimate reasons may include, but are not limited to, responding to lawful subpoenas or court orders; investigating misconduct (including research misconduct); determining compliance with Caltech policies and the law; and locating electronic messages, data, files, or other records related to these purposes. Users must therefore understand that any electronic messages, data, files, and other records generated by, stored, or maintained on Caltech IT resources may be electronically accessed, reconstructed, or retrieved by Caltech even after they have been deleted.

Caltech personnel who wish to access the content of electronic mail, data, files, or other records generated, stored, or maintained by any user must request authorization as follows: (1) from the provost for any situations that require access to electronic material associated with faculty and other academic personnel; (2) from the associate vice president for human resources for staff and postdoctoral scholars at campus or the JPL director for human resources for employees and postdoctoral scholars at JPL; (3) from the vice president for student affairs for students; or (4) from the general counsel for the purposes of complying with legal processes and requirements or to preserve user electronic information for possible subsequent access in accordance with this policy. In all cases, the Office of the General Counsel should be consulted prior to deciding on whether to grant access. In the case of a time-critical matter, if the authorizing official is unavailable for a timely response, the general counsel may authorize access. Users of Caltech IT resources are advised that some authorizations already have been granted. For example, the Caltech information security team has certain authority to monitor Caltech IT resources for

cybersecurity purposes.

In conclusion, the use of Caltech electronic information resources is a privilege, not a right, and Caltech may revoke this privilege or decline to extend this privilege at any time.

Suspected illegal acts involving Caltech electronic information resources may be reported to governmental authorities and may result in prosecution by those authorities. Any questions concerning the appropriate use of any of Caltech's electronic information resources or relevant Caltech policies should be directed to the provost, the general counsel, the chief information officer, the associate vice president for human resources, the JPL director for human resources, the dean of undergraduate students, or the dean of graduate studies.

Report any suspected security incident or violation via email (security@caltech.edu) or, at JPL, by calling the JPL Helpdesk (4-HELP) or via email (abus

Related Policies:

- Nondiscrimination and Equal Employment Opportunity Policy
- Sex Discrimination
- Unlawful Harassment, Discrimination, and Abusive Conduct Policy
- IMSS Security Policies
- Caltech Network Policy
- Confidentiality of Private Information Policy
- Vulnerability Scan Policy
- DMCA Infringement Policy
- Safeguarding Export Controlled Data Policy
- Email Policies
- Political Activities Guidelines
- Guidance on the Use of Generative AI and Large Language Model Tools

COMPLIANCE WITH EXPORT LAWS AND REGULATIONS

The mission of the California Institute of Technology is to expand human knowledge and benefit society through research integrated with education. We investigate the most challenging, fundamental problems in science and technology in a singularly collegial, interdisciplinary atmosphere, while educating outstanding students to become creative members of society.

Export control laws and regulations as referred to in this Policy include a number of federal laws and regulations that impact an export or import transaction such as those of the Departments of State, Commerce, Treasury, Defense, Energy and U.S. Customs. These laws have existed for many years. Events around the world, however, have pushed national security concerns to the forefront. The U.S. government has responded to global security concerns by tightening the export control regulations that govern the transfer of U.S. strategic technology for national security and foreign policy reasons and in furtherance of US economic objectives. Moreover, Presidential National Security Directives mandate the establishment of research security programs to protect against foreign government interference

to address intellectual property theft, malign foreign talent programs, and to protect critical technologies that can be used by adversaries in ways that can jeopardize our national security.

The export control laws are intended to control the transfer of sensitive information or goods to individuals, entities or countries of concern. The laws impose restrictions dependent on the type of information or goods and the identity of the foreign person or entity. The regulations contain a fundamental research exclusion and specific university exemptions that allow most of the research activities being performed at U.S. universities to be carried out without the need of export licenses or other restrictions, subject to certain conditions.

The National Policy on Transfer of Scientific, Technical and Engineering Information, i.e., Presidential National Security Decision Directive 189 (NSDD 189) recognizes the important contributions that U.S. universities make in science and engineering that allow our nation to remain innovative and competitive. This National Policy provides the framework for the fundamental research exclusion. NSDD 189 defines fundamental research as:

Basic and applied research in science and engineering where the resulting information is to be shared broadly within the scientific community, as distinguished from proprietary research and from industrial development, design, production, and product utilization, the results of which ordinarily are restricted for proprietary or national security reasons.

The fundamental research exclusion applies to basic and applied research in science and engineering performed by universities, so long as that research is carried out openly and without restrictions on publication or access to or dissemination of the research results.

The fundamental research exclusion applies only to research conducted in the United States. This exclusion allows most of the activities conducted at Caltech to be performed without the need for an export license. However, there are certain activities and information that are not covered by the fundamental research exclusion and remain subject to the export control laws and regulations.

Caltech is an institution of higher learning conducting fundamental research in science and engineering. The exclusion allows most of the activities conducted in the United States to be performed without the need for an export license. While the fundamental research exclusion applies to much of the research carried out at Caltech, there are, nonetheless, certain activities and information that are not covered by the fundamental research exclusion and remain subject to the export control laws and regulations.

Examples of activities not covered by the fundamental research exclusion are:

- Receipt of third-party export-controlled information which requires that appropriate measures be taken to ensure that the information is properly safeguarded;
- Under certain conditions, disclosure of specific information and the provision of specific types of services to foreign persons (e.g., individuals who are not U.S. citizens, legal permanent residents,

or U.S. legal entities) inside the United States ("deemed exports");
- Engagement in specific activities with persons and entities while traveling abroad, even if the information relied upon is publicly available;
- The export of controlled items and information outside the United States including hardware, software, biological and chemical materials, and technical data; and
- Financial transactions or other dealings involving prohibited parties or sanctioned countries.

The export control laws and regulations apply to covered research activities regardless of whether they are unfunded or funded, e.g., by government contract or grant.

The export control laws are administered by the U.S. Department of Commerce through its Export Administration Regulations (EAR – dual-use items), the U.S. Department of State through its International Traffic in Arms Regulations (ITAR – space and military items), and the U.S. Department of Treasury through its Office of Foreign Assets Control (OFAC – economic and trade sanctions). These laws control the conditions under which certain information, technologies, and commodities can be transmitted overseas to anyone, including U.S. citizens, or to a foreign person on U.S. soil. Caltech is committed to complying fully with these federal laws and regulations.

Caltech takes its commitment to openness in research very seriously. Caltech's policy, as set forth in the Faculty Handbook, does not allow acceptance of any agreement, including a government contract or grant, that impinges on Caltech's ability to freely publish and otherwise disseminate the results of its research. The transfer of export-controlled information or items requires added levels of security, safeguarding responsibilities and, in some instances, government authorization. For these reasons, research activities in which students will be provided with export-controlled technology (including technical data, software or items) with ITAR or high EAR (e.g., 500- and 600-series Export Control Classification Number*) controls or licensing requirements, must be formally approved by the Office of the Provost.

* Export Control Classification Numbers (ECCNs) are described on the Department of Commerce's website here: https://www.bis.gov/ear

Caltech has an established Export Compliance Office and has an appointed Export Compliance Manager who also functions as Caltech's Empowered Official. The Empowered Official is the person who has legal authority to sign export control license applications and other requests for export approval on behalf of Caltech and is the person responsible for developing and implementing export compliance programs, campus procedures, awareness and training programs for faculty and staff.

All faculty and staff must comply fully with all applicable export control laws and regulations. (The Jet Propulsion Laboratory, a federally funded research and development center, has a separate Export Compliance Policy.) Noncompliance may result in violations

that can subject both the individual and Caltech to civil sanctions and criminal penalties.

It is the responsibility of Caltech faculty and staff to ensure Caltech's compliance with this policy and all related Caltech procedures.

The Export Compliance Manager has been designated as the primary contact for export control issues. For more information or for questions, please contact:

Grace Fischer-Adams, Export Compliance Manager (626) 395-2907, gracefa@caltech.edu or the Export Compliance Office staff at (626) 395-2641 or exportcompliance@caltech.edu.

* Export Control Classification Numbers (ECCNs) are described on the Department of Commerce's website here: https://www.bis.gov/ear

CONFLICTS OF INTEREST

1.0 Policy

The mission of Caltech is to expand human knowledge and benefit society through research integrated with education. In pursuit of this mission, Caltech adheres to its Code of Conduct and strives for the highest level of integrity and public confidence. Caltech's integrity rests on the personal integrity of each of us who is called upon to act on behalf of Caltech. Caltech, including JPL, is committed to ensuring that decisions made on its behalf reflect the highest ethical standards and that its research and instruction remain a rigorous and open inquiry, unencumbered by conflicts of interest, real or perceived, that might affect the sound judgment of its trustees, officers, senior management, faculty, students, postdoctoral scholars, staff, JPL employees, and visitors. Each of us, therefore, is responsible for identifying and resolving conflicts between personal and institutional interests. We each must act in the best interests of Caltech and refrain from taking part in any transaction where we do not believe in good faith that we can act impartially.

Personal and institutional conflicts of interest may affect Caltech's trustees, officers, management, faculty, postdoctoral scholars, students, staff, JPL employees, and visitors. A personal conflict of interest is a situation that may compromise an individual's personal judgment and ability to remain objective in carrying out Caltech business due to a relationship that directly or indirectly affects the interest of the individual or a Family Member[1].

Institutional conflicts of interest differ from personal conflicts of interest. An institutional conflict of interest arises when the research, teaching, outreach, or other activities of Caltech may be compromised because of a financial, business or other interest held by Caltech that may affect, or appear to affect, research, teaching, outreach, or other Caltech activities in question.

Caltech has established its conflict of interest policies and procedures that apply to all Caltech employees, including faculty, to ensure compliance with Caltech's ethical standards as well as with the laws, rules, and regulations that govern Caltech activities, while fostering and sustaining an environment of openness and integrity.

1 *Family Member is defined as spouse, domestic partner, or children*

2.0 Personal Conflicts of Interest

Each situation that presents an actual or potential for conflict of interest must be fully disclosed to Caltech and avoided or adequately managed or eliminated before moving forward. Conflicts of interest also include conflicts of commitment, which are situations in which outside activities, whether paid or unpaid, interfere with an employee's primary obligation and commitment to Caltech. Everyone has a responsibility to disclose covered[2] outside activities and should take care to avoid conflicts of commitment. There are also special considerations, including required disclosure of outside activities, affiliations and appointments, that may also apply to those performing federally-sponsored research at Caltech. Federal agencies and private research sponsors have an interest in ensuring that researchers supported on their awards devote appropriate personal time and effort to funded research activities and that time and effort specifically allocated to them is not diverted to other activities The Division Chairs and the Office of Research Policy at Campus and the Ethics Office at JPL serve as resources to researchers who have questions concerning whether particular outside activities they are considering may pose a conflict of commitment.

2 *Outside activities are "covered" when they reasonably appear to be related to the employee's duties or expertise in their role at Caltech (i.e. institutional responsibilities), impact Caltech's reputation, or impair the employee's ability to perform their job.*

Faculty, postdoctoral scholars, visiting researchers, staff, and JPL employees are required to comply with this policy and must complete Caltech's Disclosure Form (DFIC) within 30 days of hire and on an annual basis. Changes or additions to responses in the DFIC must be submitted within 30 days of acquiring a new interest, beginning a new approved activity, or whenever there are any changes in previously disclosed interests or activities.

In academic research, the term conflict of interest refers especially to situations in which financial or other personal considerations may compromise, or may have the appearance of compromising, an investigator's professional judgment in developing, conducting or reporting research. Biases can affect collection, analysis, and interpretation of data, hiring of employees, procurement of materials, sharing of results, choice of protocol, and the use of statistical methods. Conflicts of interest can affect all scholarly fields.

The broad principles in this policy encompass a variety of situations, many of which do not fall into patterns for which specific guidelines may be established. Conflicts of interest inevitably arise from time to time in everyday business life; some may appear to be inconsequential or may even be advantageous to Caltech. It is important, however, that all employees make timely and accurate disclosure of financial interests and covered outside activities. Each employee should apply their sense of integrity and common sense to disclose any circumstances that are, may become, or may give the appearance of a possible conflict of interest. Supplementing this broad policy statement are the following rules to be observed on

specific matters:

2.1

Each employee has a duty to act in the best interest of Caltech and avoid actions that would call into question the integrity of the employee or Caltech.

2.2

An employee who has, either directly or through Family Member or business connection, a Material Financial Interest[3] in suppliers of goods or services, or in entities doing business or seeking to do business with Caltech, should not act on behalf of Caltech in any transaction involving that interest. No employee should participate in the evaluation, selection, award, or administration of a contract or other agreement with any entity with whom employment or potential employment or other business arrangement is occurring or being considered.

3 *Material Financial Interest is defined in the DFIC.*

2.3

An employee should avoid outside activities involving obligations that may conflict or appear to conflict with Caltech interests, including its interest in the employee's full- or part-time services (i.e., a conflict of commitment). Outside activities requiring disclosure include, but are not limited to, paid or unpaid directorships, external academic appointments, editorial positions, service on advisory boards, consulting or similar arrangements, and other outside employment. Campus staff and JPL employees and postdoctoral scholars are required to obtain approval prior to engaging in outside activities. Campus staff and postdoctoral scholars must complete the Request for Outside Activity form as required in Personnel Memorandum PM 9-3. JPL Employees and JPL postdoctoral scholars should submit outside activity requests electronically and may contact the JPL Ethics Office for assistance.

2.4

To avoid the appearance of a conflict of interest, an employee should provide full disclosure of any business or financial enterprise or activity in which they are involved that might influence, or appear to influence, their official decisions or actions on Caltech matters.

2.5

An employee should refrain from personal activities (including, but not limited to, the purchase or sale of securities, real property, or other goods or services) in which they could use or might appear to have the opportunity to use, for personal gain, confidential information or special knowledge gained as a result of their relationship with Caltech.

2.6

Employees should refrain from the unauthorized disclosure of nonpublic information they have access to as a result of their position at Caltech and must not use nonpublic information accessed through the performance of a sponsored contract or other agreement for personal gain.

2.7

Employees must not use Caltech resources for their personal benefit or for the benefit of any other person. Incidental personal use

of resources is authorized by Caltech. See Acceptable Use of Electronic Information and Computing Resources Policy and JPL Rules for requirements on incidental use and activities at JPL.

2.8

It is sound practice to discourage gifts and favors from persons or organizations with whom Caltech has a business relationship or with whom a business relationship is being considered. Personal gifts and gratuities with more than $25 should be tactfully declined or returned to the offeror to avoid any appearance or suggestion of improper influence. Any employee involved in awarding or administering contracts or other agreements funded with Federal or other government funds should keep in mind that applicable laws contain prohibitions against soliciting or accepting gratuities, favors, or anything of monetary value from contractors or potential contractors.

Leisure trips with representatives of vendors are not appropriate, even when a staff employee pays a fee to the vendor to participate in such trips. See the JPL Gifts and Gratuities policy for additional guidance on gifts at JPL.

2.9

No employee should act in any Caltech matter involving a Relative[4] or an individual with whom they have a similar relationship (family member), including, but not limited to, matters affecting a family members' employment or evaluation or advancement at Caltech. Family members include an employee's parents, grandparents, spouse, domestic partner, children, brothers, sisters, in-laws, an individual with whom the employee has a significant personal relationship, and an individual who is a member of the employee's household, or who cohabitates with the employee. The employment of Relatives as that term is defined in Personnel Memorandum (PM 9), is subject to the conditions and restrictions described in PM 9, including the requirement to complete the Nepotism Evaluation process whenever a relative of an employee is considered for employment in the same organization as the employee.

In addition to making required disclosures, any employee who believes that they have other financial interests or activities that may conflict with these rules or otherwise create a conflict of interest, should make an appropriate disclosure. You may also report concerns about possible conflicts of interest on the part of others by calling the Campus Hotline at (626) 395-8787 or submitting a hotline form. JPL employees may also report concerns using the JPL Ethics Help line at (866) 405-7536. Further direction for JPL employees is available by reviewing Laboratory policies and requirements and seeking guidance and/or reporting conflict of interest concerns by contacting the JPL Ethics Office at (818) 354-6338 or email at Ethics-Office@jpl.nasa.gov.

4 Relatives are defined as any family member, including but not limited to, parents, grandparents, spouses, domestic partners, children, siblings, in-laws, an individual with whom the employee has a significant personal relationship, any individual who is a member of the employee's household, or who cohabitates with the employee.

3.0 Additional Faculty Responsibilities

It is acknowledged that, in their wider roles as academicians and professionals, the faculty may be subject to conflicts of interest and commitment that are not within the scope of a policy that is designed to address conflicts of interest in the employer-employee setting. For example, this policy is not designed to address conflicts that may be encountered in service to a professional society or peer review of journal submissions or of research grant applications. Other activities not covered by this policy are best handled within the ethical guidelines established by the Faculty Handbook. Faculty members must be aware of potential conflicts to ensure an open and productive environment for research and teaching. Conflicts of interest may arise when faculty members have the opportunity to influence Caltech's business decisions or when outside relationships may, or may appear to, compromise the integrity of decisions made as teachers and researchers. A faculty member's general commitment to Caltech requires that members perform their responsibilities to Caltech and appropriately use their own judgment in deciding whether to engage in a variety of extramural activities, within the confines set forth in the Faculty Handbook and any obligations prescribed by research sponsors. As a result, Caltech relies on its faculty to be alert to the possible effects of outside activities and financial interests on the integrity of their decisions and on their ability to fulfill their obligations to Caltech and to federal and private research sponsors. Accordingly, in addition to the conflict rules set forth above, the following guidance is provided for faculty:

3.1

Disclosure is imperative if the faculty member directs students in a research area and, as a result, the faculty member intends to realize financial gain. An example is a research area within the ambit of a business in which the faculty member has a Significant Financial Interest[5] or is employed by or acts as a consultant for the business. Any involvement of undergraduates, graduate students, or postdoctoral scholars in the outside professional activities of the faculty member directing the student's or postdoc's research must be reviewed by the Office of Research Policy and specifically approved, in advance, by the division chair and vice provost, as applicable. The student or postdoctoral scholar must also sign a written Lab Member Disclosure to signify understanding of the issues involved.

5 Significant Financial Interest is defined in Caltech's Policy and Procedures for Managing Conflict of Interest Requirements Imposed by Federal Sponsors.

3.2

Disclosure is mandatory if the faculty member has a Significant Financial Interest in or a commitment to a for-profit, not-for-profit, or governmental entity (Entity) that is related to the faculty member's duties or expertise in their position at Caltech (i.e., institutional responsibilities).

3.3

Disclosure is mandatory if the faculty member is to receive sponsored support for research from or have another relationship with an Entity for which the faculty member is a consultant, or in which the

faculty member has a significant financial interest.

4.0 Conflict of Interest Requirements Imposed by Federal Agency Sponsors

Certain Federal sponsors have issued specific rules regarding the disclosure of significant financial interests, the management of financial conflicts of interest and conflicts of commitment, the disclosure of all resources made available to a researcher in support of their research, and all academic and industry roles and appointments. Such disclosures, and consideration by Caltech of their implications for research integrity, are a condition for submitting proposals and accepting awards of financial support from these agencies. Members of the Caltech community proposing or working on any activity funded by a federal sponsor are required to comply with Caltech's Policy and Procedures for Managing Conflict of Interest Requirements Imposed by Federal Sponsors, and other sponsor disclosure requirements. The Office of Research Policy at Campus and the Ethics Office at JPL should be consulted whenever researchers have questions concerning whether and how certain information should be disclosed in connection with the submission of proposals for federal funding and during the lifecycle of an award.

5.0 Institutional Conflicts of Interest Policy

Caltech has many legitimate interests that may at times conflict. Management of institutional conflicts of interest is by its very nature more complex than that of personal conflicts of interest. External relationships with sponsors and supporters of Caltech, the local community's acceptance of economic development activities, Caltech obligations as a charitable organization receiving preferential tax treatment, and the perception of Caltech's teaching, research, and academic missions all impact how potential conflicts of interest are managed. The examples and issues presented below do not necessarily constitute unacceptable conflicts of interest. Each case must be judged on the facts and merits of the relationship with an eye to what reasonable individuals outside Caltech might consider to be an unacceptable conflict of interest. Any activity that may bring into question Caltech's reputation, integrity, or objectivity should be considered for possible conflicts of interest. The following are examples of potential situations that may give rise to institutional conflicts of interest:

5.1

Significant gifts to Caltech from a commercial sponsor of research may raise questions about the influence of the company on Caltech's research programs and how they are managed. Similar concerns arise when individual companies sponsor research or provide significant consulting income to a significant number of faculty members within a single academic division. Particular attention should be given to identifying and managing potential conflicts arising when a company sponsors research involving human participants and Caltech has a financial or business interest in the company.

Gifts or the promise of gifts, in exchange for favorable terms on a technology license or a first look at intellectual property may pose a problem.

The acquisition of goods and services for Caltech represents a large portion of Caltech's expenditures. Purchasing goods and services from companies that sponsor research at Caltech, or who are licensees of Caltech technology, may raise issues similar to those raised by large gifts from commercial sponsors.

A potential institutional conflict of interest exists simply by Caltech having a license agreement with, or an equity position in, a company sponsoring a faculty member's research. In these situations, there may be, or may appear to be, a bias to accept terms and conditions that would facilitate the company's success.If you identify a situation that may pose an institutional conflict of interest, you should report the situation to either the Vice President and Chief Operating Officer or the Provost on campus or to the associate director for business at JPL. You may also make a report by calling the Campus Hotline at (626) 395-8787 or submitting a hotline form, calling the JPL Ethics Office at (818) 354-6338, the JPL Ethics Help line at (866) 405-7536 or sending an email to Ethics-Office@jpl.nasa.gov

If you identify a situation that may pose an institutional conflict of interest, you should report the situation to either the vice president for administration and chief financial officer or to the provost on campus or to the associate director for business at JPL. You may also make a report by calling the Campus Hotline at (626) 395-8787 or submitting a hotline form, calling the JPL Ethics Office at (818) 354-6338.

DISABILITY AND REASONABLE ACCOMMODATION

1.0 Policy

It is Caltech's policy to comply fully with the Americans with Disabilities Act (ADA), the Rehabilitation Act, the Pregnant Workers Fair Act, and other applicable federal and state laws to ensure equal opportunity for otherwise qualified individuals with disabilities, including disabled veterans, as well as known limitations related to pregnancy, childbirth, or related medical conditions (pregnancy related conditions). Caltech does not discriminate based on physical or mental disabilities and is committed to ensuring that there is no unlawful discrimination or harassment in any of its academic or employment programs, services, activities, or in any terms and conditions of employment.

As required by law, Caltech will make reasonable accommodations to otherwise qualified individuals with known disabilities, including students, faculty, postdoctoral scholars, staff, volunteers, interns, and job applicants, to ensure equal employment opportunities and equal access to Caltech educational programs, services, activities, and facilities unless doing so would constitute an undue hardship or a fundamental alteration. Caltech also will provide reasonable accommodations to employees with pregnancy-related conditions consistent with federal and state law and Caltech's Sex Discrimination Policy.

Caltech also, as appropriate, will conduct a fair, timely, and thorough investigation into complaints within the scope of this policy to determine what occurred and take reasonable steps to remedy the effects of any discrimination and prevent recurrence of the behavior. Caltech provides all parties with appropriate due process and reaches reasonable conclusions based on the evidence collected. Caltech takes appropriate action, including disciplinary measures, when warranted.

2.0 ADA Coordinators

The following individuals have been designated to coordinate Caltech's efforts to comply with and carry out its responsibilities under applicable disability laws and Caltech policy (ADA coordinators). Individuals who believe they have been discriminated against based on their disability or who wish to request accommodations should contact the appropriate Caltech ADA coordinator.

ADA Coordinator for Undergraduate and Graduate Students:
Jocelyn Vargas, (626) 395-8375
Accessibility Services Specialist

ADA Coordinator for Faculty:
Stacey Scoville, (626) 395-6320
Administrator, Office of the Provost

ADA Coordinators for Staff, Postdoctoral Scholars, Volunteers, and Interns at Campus:
Ofelia Velazquez-Perez, (626) 395-3819
Director, Employee and Organizational Development

Taynora Lee, (626) 395-5740
Associate Director, Disability and Leave Administration

ADA Coordinators for Employees, Volunteers, Candidates, and Interns at JPL:
Cynthia Ordonez, (626) 720-1640
Human Resources Representative

Xochipilli Castro, (626) 390-8391
Human Resources Representative

3.0 Reasonable Accommodations

Caltech will provide reasonable accommodations that are appropriate and consistent with legal requirements. In evaluating requests for accommodations, Caltech will engage in a timely and good-faith interactive process with the requesting individual to determine what, if any, accommodations should be provided. Caltech has the right to request documentation supporting an accommodation request, including documentation of the disability when the disability or the need for accommodation is not obvious.

4.0 Right to File a Grievance

Anyone who witnesses, experiences, or is otherwise aware of conduct that they believe to be in violation of this policy, including retaliation, is urged to immediately report it, or to request assistance and guidance. Complaints or concerns about disability discrimination and harassment should be reported to one of the ADA coordinators listed

above, the Equity and Title IX Office at campus, or the Employee Relations Group at JPL. Concerns related to harassment and discrimination based on disability will be resolved under the Institute's Unlawful Harassment and Abusive Conduct policy and procedures.

In addition, after engaging in the interactive process and after Caltech has determined whether a reasonable accommodation is available, an individual requesting an accommodation who disagrees with the decision may file a grievance under the Disability and Reasonable Accommodation Grievance Procedures.

5.0 Right to File Complaint with Outside Agency

Employees and applicants may also file a complaint with the U.S. Equal Employment Opportunity Commission, the California Civil Rights Department, the U.S. Department of Labor, Office of Federal Contract Compliance Programs, or the U.S. Department of Education, Office for Civil Rights. Students may file complaints with the U.S. Department of Education Office for Civil Rights at (415) 486-5555 (or OCR.SanFrancisco@ed.gov) or (800) 421-3481 (or OCR@ed.gov). Complaints may also be directed to the Bureau for Private Postsecondary Education at bppe.ca.gov/.

Related Policies and Procedures:

- Nondiscrimination and Equal Employment Opportunity Policy
- Unlawful Harassment and Abusive Conduct Policy
- Procedures for Complaints of Unlawful Discrimination, Harassment and Retaliation
- Disability and Reasonable Accommodation Grievance Procedures

ENVIRONMENTAL HEALTH, AND SAFETY

1.0 Policy

Caltech is committed to conducting activities in a manner that promotes the safety and health of faculty, staff, postdoctoral scholars, students, and visitors; applies sound practices in environmental stewardship; and minimizes risk to Caltech property. Activities at Caltech are to be conducted in accordance with the following guiding principles:

- The responsibility for implementing and maintaining a safe environment rests on all faculty, staff, postdoctoral scholars, students, and visitors at Caltech.
- Faculty, supervisors, and managers are responsible for establishing good environmental health and safety practices in their laboratories, classrooms, and workplaces and for providing safe equipment and facilities for faculty, staff, postdoctoral scholars, students, and visitors.
- All faculty, staff, postdoctoral scholars, students, and visitors are expected to keep themselves informed of conditions affecting their health and safety, participate in safety training, follow proper environmental, health and safety policies and procedures, and

report accidents, near misses and potentially unsafe or illegal conditions or practices promptly to their supervisor or manager or other appropriate office.
- Caltech activities must comply with all applicable federal, state, and local environmental, health and safety laws and regulations.

2.0 Roles and Responsibilities

Caltech has the responsibility to establish environmental, health and safety policies and procedures, and provide resources to ensure compliance with environmental and safety laws.

All managers and supervisors, both academic and administrative, at campus and JPL, are responsible for conducting operations in accordance with all applicable laws and regulations and Caltech policies, practices, and programs.

Caltech performs these functions through the following committees and administrative and management structure:

2.1 Institute Environmental Health and Safety Committee

Caltech's Institute Environmental Health and Safety Committee ("IEHSC") is responsible for recommending campus wide environmental health, and safety policies.

The IEHSC is responsible for making recommendations regarding the allocation of Institute resources so as to maintain environmental (e.g., air emissions, soil contamination, water discharges, hazardous waste management) and workplace health and safety compliance. In addition, the committee monitors developments through the campus Environmental Health, and Safety Office to ensure that Institute policies are observed, remain current, and are consistent with the anticipated changes in regulatory requirements.

2.2 Campus Environmental Health, and Safety Office

The Environmental Health, and Safety Office ("EH&S"), which reports to the associate vice president for facilities, is responsible for providing technical, regulatory, and related advisory services to the campus community. EH&S works in partnership with the academic divisions and administrative departments to develop and implement safety programs that provide technical guidance and training support relevant to the operations of the laboratories and workplace, are practical to carry out, and comply with the law. This includes general orientation in prudent laboratory practices, emergency and incident response procedures, occupational safety, and familiarity with Institute environmental health, and safety policies and procedures. EH&S also initiates site reviews to assess potential hazards and determine effective controls, and coordinates hazardous waste training and hazardous waste disposal. EH&S, working closely with the Office of the General Counsel, reviews legislation, recommends policies, provides regulatory agencies with required data and reports, and investigates and reports environmental health, and safety incidents.

2.3 Campus Division Chairs and Department Heads

The Caltech campus consists of divisions conducting research and educational activities and administrative departments supporting the operations of Caltech. It is the responsibility of each division chair and department head to ensure that their units conduct operations in accordance with applicable laws and regulations and implement Caltech's environmental health, and safety policies and procedures. Division chairs and department heads maintain responsibility for day-to-day management and implementation of their environmental health, and safety programs.

Division chairs and department heads may designate an individual with the authority to implement, manage, and enforce environmental health, and safety compliance programs within the division or administrative office. With guidance and assistance from EH&S, the responsible individual (i.e., the division chair, department head or their designee) shall manage the environmental health, and safety activities in the division or department.

2.4 JPL Office of Safety and Mission Success

The Office of Safety and Mission Success at JPL ("JPL OSMS") establishes and leads the Environmental Health, and Safety and Mission Assurance Programs for projects, programs and major tasks. JPL OSMS appropriately manages risks and enhances the probability of mission safety and success. In this capacity, JPL OSMS is an independent organization, reporting directly to the JPL director. JPL OSMS continually assesses risk and provides infrastructure to ensure that JPL maintains compliance with the JPL Prime Contract and applicable federal, state, and local environmental health, and safety requirements. JPL OSMS applies knowledge, innovation, and independence to achieve successful missions that inspire the world while safeguarding JPL's people, assets, and reputation.

2.5 JPL Environmental Health, and Safety Program Management

The JPL Occupational Safety Program Office, the JPL System Safety Program Office, and the JPL Environmental Affairs Program Office are chartered with establishing and leading programs related to occupational safety, systems safety, and environmental compliance, respectively, and are tasked with appropriately sharing in the management of risks and enhancing the probability of mission safety and success. These JPL program offices, working closely with the Office of the General Counsel, review legislation, regulations and contracts, recommend policies, provide regulatory agencies with required data and reports, and investigate and report environmental health, and safety incidents. Each of the environmental health, and safety program management offices also implement and monitor compliance with JPL Rules! and applicable regulations.

2.6 Campus and JPL Manager and Supervisor Responsibilities
Managers are responsible for ensuring that areas under their management have adequate resources for environmental health, and safety programs, practices, and equipment. Managers are also responsible to ensure that those areas under their management are in compliance with Caltech's environmental health, and safety policies, practices, and programs.

Supervisors, including principal investigators ("PIs"), and any other persons who direct the activities of others, with guidance and assistance from the environmental health, and safety offices listed above, are responsible for implementing environmental health, and safety policies, practices, and programs, ensuring that workplaces, including laboratories and equipment, are safe and well-maintained, training and informing employees, students, and visitors about workplace-specific hazards and safety procedures, providing personal protective equipment (and ensuring its proper use), correcting violations, investigating incidents, near misses and complaints, overseeing proper storage and disposal of hazardous materials, enforcing policies (including appropriately disciplining employees and students who violate environmental and safety requirements), and appropriately documenting training, activities, and processes.

Faculty are responsible for the safety of work undertaken in their laboratories. Faculty
members may designate a qualified individual, known as a Safety Coordinator, and empower that individual to assist in the day-to-day safety activities within their research groups. Faculty members, however, remain fully responsible for the safe conduct of work in their laboratories.

2.7 All faculty, staff and students
All faculty, staff, postdoctoral scholars, and students at campus and JPL are responsible for:

- Keeping themselves informed of conditions affecting their health and safety,
- Participating in safety training programs as required by the governing organization's policy and their supervisors,
- Performing work in a safe and prudent manner,
- Adhering to health and safety practices in their workplaces, classrooms, and laboratories, and,
- Advising of or reporting potentially unsafe practices, illegal activities, or serious hazards in the workplace, classroom or laboratory, and cooperatively participating in the investigation and/or remediation of any incidents.

The success of Caltech's environmental, health and safety management activities requires the active involvement of individuals through participation in training, compliance with established environmental, health and safety procedures, and reporting hazards and potential violations.

It is the responsibility of all faculty, staff, postdoctoral scholars, and students at Caltech to disclose fully any activity that may result in a violation of environmental health, or safety laws or regulations, and to cooperatively participate in the investigation and remediation of any incidents.

2.8 Visitors and Contractors

Visitors and those who do business with Caltech either at Campus or JPL, such as contractors, consultants, and vendors, are responsible for performing their work in a manner that protects Caltech from environmental health, and safety risks, and complies with all applicable federal, state, and local laws and regulations, contractual requirements, and all applicable environmental health, and safety policies, practices, and programs.

3.0 Reporting

In matters of actual or potential regulatory enforcement action, investigations, or employee complaints, the appropriate environmental health, and safety office will work closely with the Office of the General Counsel to coordinate Caltech's response to external regulatory agencies concerned with workplace health, safety, and environmental compliance.

Any questions or concerns regarding compliance should be brought to the attention of the appropriate manager or supervisor, or to the appropriate environmental health, and safety office. Alternatively, concerns can be raised with the appropriate division chair or vice president at campus, or the OSMS director at JPL. In addition, concerns regarding Campus raised anonymously through the Campus Hotline (626) 395-8787 or (888) 395-8787 or online at Caltech Hotline or, for JPL, through the JPL OSPO 24-hour Immediate Mishap and Close Call Reporting line (IMACC) (818) 354-2141,or the Occupational Safety Program Office (OSPO).

4.0 Sanctions

All faculty, staff, postdoctoral scholars, and students must be vigilant in complying with all environmental health, and safety requirements, and to properly conduct their activities at Caltech.

Local, state, and federal laws and regulations establish civil and criminal penalties for violations of environmental health, and safety laws and regulations, including substantial fines and possible imprisonment.

Caltech views compliance with all laws, regulations, and Institute guidelines as conditions of employment. Individuals who violate this policy may be subject to disciplinary action up to and including termination of employment, student expulsion, or being permanently excluded from Caltech-controlled premises.

NONDISCRIMINATION AND EQUAL EMPLOYMENT OPPORTUNITY

1.0 Policy

Caltech is committed to equal opportunity for all persons. It prohibits discrimination and harassment in employment based on the following protected characteristics (unlawful discrimination and harassment):

- Race (includes hair texture and protective hairstyle, as well as ethnicity)
- Color
- Religion (includes religious dress and grooming practices)
- Sex/gender (includes pregnancy, childbirth, breastfeeding, and/or related medical conditions)
- Gender identity and gender expression
- Sexual orientation
- Marital status
- Medical condition (genetic characteristics, cancer, or a record or history of cancer)
- Military or veteran status
- National origin (includes language use and possession of a driver's license issued to persons unable to prove that their presence in the United States is authorized under federal law)
- Ancestry (includes caste)
- Disability (mental and physical, including HIV/AIDS, cancer, and genetic characteristics)
- Genetic information
- Request for family care leave
- Request for leave for a serious health condition
- Request for Pregnancy Disability Leave
- Domestic violence victim status
- Age (40 and over)
- Criminal background as required under the Fair Chance Act
- Any other factor protected by federal, state, or local law
- Association with an individual who is in one of the foregoing protected characteristics
- Reproductive health care decision-making

It is the policy of Caltech to provide a work and academic environment free of discrimination as required by federal and state law. Discrimination is different, less favorable treatment based on a protected characteristic listed above and/or applying policies and practices that have an adverse impact on individuals based on protected characteristics. Harassment on the basis of any legally protected characteristic is a form of discrimination and is likewise prohibited by this policy.

The law prohibits discrimination by co-workers and third parties as well as supervisors and managers. Interns, volunteers, and persons performing services under a contract with Caltech are also covered by this policy. Caltech will take all reasonable steps to eliminate discrimination and harassment in its work and academic environment.

Complaints concerning sex- and gender-based discrimination and harassment and sexual misconduct are governed by the Sex- and Gender-Based Misconduct Policy.

Caltech is an equal employment opportunity and affirmative action employer, and consistent with Caltech's obligations as a Federal contractor and in furtherance of its education and research mission, will actively recruit and work to ensure equal employment opportunities for protected veterans, individuals with disabled veteran status, and otherwise qualified persons with disabilities. Caltech will hire, transfer, recruit, train, and promote based on the qualifications of the individual to ensure equal consideration and fair treatment of all. All other employment actions, such as work assignments, appointments, compensation, evaluations, training, benefits, layoffs, and terminations are governed by this policy. Personnel actions will be reviewed to ensure adherence to this policy.

Individuals who violate this policy may be subject to disciplinary action up to and including termination of employment, student expulsion, or being permanently excluded from Caltech-controlled premises.

2.0 Responsible Administrators

Caltech's associate vice president for human resources and JPL's director for human resources have been assigned to direct the establishment of and to monitor the implementation of personnel procedures to guide our affirmative action programs. They will have responsibility to review and update the affirmative action plans annually, including responsibility for the audit and reporting system. A notice explaining Caltech's policies will remain posted.

In addition, Caltech has designated equal opportunity coordinators (EO coordinators) who are responsible for assisting with and coordinating the education and compliance efforts relating to equal opportunity and nondiscrimination laws and Caltech policies. The following individuals have been designated as equal employment opportunity coordinators: the provost is the coordinator for faculty; the assistant vice president for human resources is the coordinator for campus staff, including campus postdoctoral scholars, and volunteers; the associate deans of students are the coordinators for undergraduate students and interns; the dean of graduate studies is the coordinator for graduate students and interns; and the director for human resources at the Jet Propulsion Laboratory is the coordinator for employees, postdoctoral scholars, interns, and volunteers assigned there. The assistant vice president for equity and equity investigations, who manages the Equity and Title IX Office, has been designated as Caltech's Title IX coordinator. The contact number is (626) 395-3132, email: equity@caltech.edu, or the office in Room 205, Center for Student Services. The Title IX coordinator is supported by three deputy Title IX coordinators for faculty, staff, and students on campus, and a deputy Title IX coordinator for employees at the Jet Propulsion Laboratory (JPL). Further information is available on the website of the Equity and Title IX Office.

Managers and supervisors are responsible for monitoring decisions regarding personnel actions to ensure that these decisions are based solely on factors other than protected characteristics and on legitimate, nondiscriminatory job requirements for the position in question and the reasonableness of any necessary accommodations for persons with a disability.

3.0 Reporting Concerns and Complaints

Individuals who become aware of, witness, or experience conduct they believe to be in violation of this policy are urged to contact any of the above-mentioned coordinators, the Caltech Equity and Title IX Office, or JPL Employee Relations Group immediately.

In addition, concerns may be reported anonymously to any of the anonymous reporting options listed below. Complaints will be investigated promptly, in accordance with the Procedures for Complaints of Unlawful Discrimination, Harassment and Retaliation ("Unlawful Harassment Procedures"). Confidentiality will be maintained to the extent possible.

Any employee in a supervisory role, including faculty, must promptly report **all** alleged harassment, discrimination, sex- and gender-based misconduct, and retaliation, regardless of its alleged severity or frequency, to the Equity and Title IX Office at campus or Human Resources at JPL, which will provide guidance and advice. In addition, other employees qualifying as responsible employees under the Sex- and Gender-Based Misconduct Policy, must promptly report any instance of prohibited conduct to the Equity and Title IX Office or the Deputy Title IX coordinator for JPL, as appropriate.

4.0 Anonymous Reporting

Caltech provides the following resources for anonymous reporting:

- Caltech Hotline : (626) 395-8787 or (888) 395-8787
- Equity and Title IX Office Online Report a Concern Form (complete anonymously): Online Report Form | Equity and Title IX Office (caltech.edu)
- JPL Ethics Hotline: (818) 354-9999
- JPL Protective Services Division's Workplace Violence Hotline: (818) 393-2851
- For either Campus or JPL by submitting a compliance Hotline Contact Form

A report is considered anonymous if the reporting party does not share their name or contact information. If a reporting party chooses to provide their name or contact information, the report will not be treated as anonymous and they will receive information about support resources, reporting options, and notification of an investigation, if an investigation is pursued.

5.0 Reporting to Outside Agencies

In addition, employees who believe they have been unlawfully harassed on the basis of a protected characteristic have the right to file a complaint with the federal Equal Employment Opportunity Commission or the California Civil Rights Department, which have the authority to remedy violations. Employees, students, and others participating in Caltech's educational programs and activities may file complaints with the U.S. Department of Education Office for Civil Rights at (202) 607-1600, ocr.seattle@ed.gov, or (800) 421-3481 or OCR@ed.gov. Complaints may also be directed to the Bureau for Private Postsecondary Education at bppe.ca.gov.

6.0 Investigation of Complaints

Caltech will conduct a fair, timely, and thorough investigation into complaints within the scope of this policy to determine what occurred and take reasonable steps to remedy the effects of any discrimination and prevent recurrence of the behavior. Caltech provides all parties with appropriate due process and reaches appropriate conclusions based on the evidence collected. Caltech takes appropriate action, including disciplinary measures, up to and including termination, student expulsion, or being permanently banned from Caltech premises, when warranted.

7.0 Policy against Retaliation

No one may intimidate, threaten, coerce, or discriminate against any individual for the purpose of interfering with any right or privilege secured by this policy or the related procedures, or because the individual has made a report or complaint, testified, assisted, participated, or refused to participate in any manner in any action or process under this policy or the related procedures. Intimidation, threats, coercion, or discrimination for the purpose of interfering with any right under this policy or the related procedures constitutes retaliation. The rights and privileges secured under this policy and the related procedures include but are not limited to: (i) filing or assisting in the filing of a complaint or report of a suspected violation of this policy; (ii) opposing any act or practice made unlawful by any federal, state or local laws requiring equal opportunity; (iii) participating, assisting, or otherwise cooperating in an investigation, compliance review, hearing, or any other activity related to a violation of this policy or administration of any federal, state, or local law requiring equal opportunity; and/or (iv) exercising any legal right protected by federal, state, or local law requiring equal opportunity.

The following actions do not constitute retaliation: the exercise of rights protected under applicable law or Caltech policy or Caltech's charging an individual with a policy violation for making a materially false statement in bad faith in the course of a resolution process. A determination that a respondent was or was not responsible for alleged misconduct alone is not sufficient to conclude that any party made a materially false statement in bad faith.

Complaints of retaliation will be addressed under the Procedures for Complaints of Unlawful Discrimination, Harassment, and

Retaliation.

8.0 Informational Resources
Information on equal employment opportunity and nondiscrimination, as well as copies of Caltech's Nondiscrimination and Equal Employment Opportunity, Unlawful Harassment and Abusive Conduct, Sex Discrimination, and Violence Prevention policies are available from Caltech's Title IX coordinator and deputy coordinators, Human Resources, Student Affairs and deans' offices, the Center for Inclusion & Diversity, resident associates, the Staff and Faculty Consultation Center, Employee & Organizational Development at Campus, and Employee Relations and the Human Resources Business Partners at JPL. The policies, available at the links below, are published in the Caltech Catalog and on the following Caltech websites: Caltech Human Resources, JPL Human Resources, Equity and Title IX Office, and Student Affairs.

9.0 Caltech's Commitment to Equal Opportunity and Nondiscrimination
To ensure equal employment opportunity and nondiscrimination, each member of the Caltech community must understand the importance of this policy and their responsibilities to contribute to its success. The president of Caltech fully supports Caltech's equal opportunity and affirmative action policies.

Related Policies and Procedures:
Related Policies and Procedures

- Sex Discrimination Policy
- Procedures for Complaints of Sex Discrimination
- Unlawful Harassment and Abusive Conduct Policy
- Procedures for Complaints of Unlawful Discrimination, Harassment and Retaliation
- Disability and Reasonable Accommodation Policy

SEX DISCRIMINATION

SECTION I: INTRODUCTION

1.0 Policy
All members of the Caltech community have the right to be treated, and the responsibility to treat others, with dignity and respect. These principles are fundamental to the educational and intellectual mission of Caltech. It is the policy of Caltech to provide a work and academic environment free of discrimination, harassment, sexual misconduct, and retaliation. Caltech will not tolerate such conduct and is committed to educating the community in ways to prevent its occurrence.

As defined in this policy, sex discrimination, sexual and gender-based harassment, and sexual misconduct, including sexual assault, sexual battery (i.e., nonconsensual sexual contact), dating and domestic violence, sexual exploitation, and stalking constitute

Prohibited Conduct and violate this policy. Such conduct generally violates Title VII of the Civil Rights Act of 1964, as amended; Title IX of the Education Code; and/or California law.

All individuals are protected against Prohibited Conduct (defined below in Section III) regardless of gender. For the purposes of this policy, the term "gender" is broadly defined, encompassing sex, sexual orientation, gender identity, and gender expression. Prohibited conduct can be committed by individuals of any gender and can occur between or among individuals of the same gender or different genders, strangers, or acquaintances as well as people involved in intimate or sexual relationships.

Caltech also prohibits retaliation against an individual who reports, submits a complaint, or otherwise participates in good faith in any matter related to this policy.

Caltech will take prompt and equitable action upon receiving a report of Prohibited Conduct to determine what occurred and will take steps to stop and remedy the effects of any such conduct and prevent its recurrence. Caltech provides all parties with appropriate due process and will take appropriate action, including disciplinary measures, when warranted, up to and including termination of employment or changes to student enrollment status, including expulsion.

Any reference in this policy to a Caltech administrator is understood to include not only that administrator but also their designee.

2.0 Scope

This Policy applies to all current students, alumni, faculty, supervisory and nonsupervisory staff, postdoctoral scholars, volunteers, interns, vendors, independent contractors, persons performing services under contract with the Institute, visitors, and any other individuals who are regularly or temporarily employed, studying, living, visiting, or otherwise participating in Caltech's educational programs or activities ("covered persons"). The requirement not to discriminate in Caltech's educational programs or activities also extends to admissions and employment. Inquiries about the application to Caltech of Title IX and its implementing regulations may be referred to the Title IX Coordinator.

This Policy applies, when both parties are covered persons, to (a) Prohibited Conduct occurring on Institute-controlled property, at Institute-sponsored events, in Institute programs or activities, or Institute-owned or controlled residential facilities, regardless of location; (b) Prohibited Conduct occurring on property or at events controlled or sponsored by Institute-affiliated organizations including student organizations, regardless of location; (c) Prohibited Conduct occurring off campus, in any location or context, when the occurrence of such alleged conduct could contribute to a hostile educational environment or otherwise interfere with a student's access to education; or (d) Prohibited Conduct occurring outside of Caltech's educational programs or activities, whether they occurred on or off campus, if, based on the allegations, there is any reason to believe that the incident could contribute to a hostile educational environment

or otherwise interfere with a student's access to education.

This policy also applies at the Jet Propulsion Laboratory (JPL). Other organizations affiliated with the Institute or that use Caltech property or resources in connection with their activities also are prohibited from engaging in Prohibited Conduct.

Even if Caltech does not have jurisdiction under this policy over the person accused of Prohibited Conduct, or the allegations reported, Caltech will take prompt action, as warranted and appropriate, to provide for the safety and well-being of the individual reporting and the campus community, including taking reasonable steps to stop and remedy the effects of the Prohibited Conduct and to prevent recurrence of the behavior.

3.0 Retaliation

Retaliation against any member of the Caltech community at any point in time for making a good-faith report of Prohibited Conduct or participating or refusing to participate in any manner in an investigation, proceeding, or hearing conducted by Caltech, or a state or federal agency is strictly prohibited. Retaliation is defined as overt or covert acts of reprisal, interference, discrimination, intimidation, or harassment against an individual or group for exercising their rights under Title IX or other federal and state laws. Threats of retaliatory action also constitute retaliation.

Retaliation does not include charging an individual with a code of conduct violation for making a materially false statement in bad faith in the course of an investigation, proceeding, or hearing related to this policy. However, a determination regarding responsibility, alone, is not sufficient to conclude that any party made a materially false statement in bad faith.

Caltech will take steps to prevent retaliation and will take prompt and appropriate corrective action to stop and remedy its effects if retaliation occurs. Individuals who violate Caltech's policy prohibiting retaliation may be subject to disciplinary action up to and including termination of employment, student expulsion or being permanently excluded from Caltech controlled-premises. Allegations of retaliation may be subject to investigation under the Procedures for Complaints of Sexual Misconduct or other Institution policies.

4.0 Preservation of Evidence of Prohibited Conduct

Prohibited conduct, as defined in this policy, may also be a crime. Individuals who have experienced sexual violence are urged to seek medical treatment as soon as possible. Sexual assault forensic exams (or rape kit tests) are available free of charge at multiple local medical centers (and facilitate both evidence preservation and any necessary medical treatment. Evidence preservation is important in case an individual would like to file a report with law enforcement, pursue civil litigation, or obtain a protective order. If an individual chooses to receive a forensic exam, they should avoid showering, bathing, douching, eating, drinking, washing their hands, or brushing their teeth until after the medical examination. Exams should be performed within 72 hours of the incident. Individuals should save all clothing worn at

the time of the assault. Each item of clothing should be placed in a separate paper bag, not a plastic bag. Individuals who have experienced sexual violence are strongly encouraged to preserve all physical and electronic evidence.

Examples of physical evidence may include clothing, bedding, contraceptives, letters, and notes. Any such items relating to an incident of Prohibited Conduct should be preserved.

Electronic evidence relating to any type of incident of Prohibited Conduct, such as texts, emails, photos, and social media posts, should be preserved.

Once an individual reports a concern or receives notification of their involvement in a report or complaint under this policy, whether as a respondent or witness, they are required to preserve any physical or electronic evidence they have. An intentional failure to preserve such evidence may be grounds for disciplinary action.

5.0 Emergency Notifications and Timely Warnings

In the event of a dangerous situation on campus that has involved an immediate threat to the health or safety of students or employees, Caltech will issue an emergency notification consistent with its emergency notification procedures. In the event that Caltech believes that there is a serious or continuing threat to the campus community, Caltech will issue a timely warning consistent with its timely warning procedures. Emergency notifications and timely warnings do not disclose the name of the victim.

SECTION II: REPORTING CONCERNS AND COMPLAINTS

6.0 Reporting to Caltech

Members of the Caltech community are encouraged to promptly report all Prohibited Conduct to Caltech or consult with a confidential resource (see Appendix: Support Resources). Reports may be made in person, by mail, by telephone, by electronic mail, or by any other means that results in the Title IX Coordinator receiving the verbal or written report. A report may also be made by completing the Report Form on the Equity and Title IX Office website at equity.caltech.edu. Reports may be anonymous and made at any time.

Anyone who witnesses, experiences, or is otherwise aware of conduct that the individual believes to be in violation of this policy, including retaliation, is urged to contact the Title IX Coordinator or a deputy coordinator immediately. Responsible Employees, as defined below, and supervisory employees, including faculty, must promptly report all alleged sexual harassment, sex and gender-based misconduct, and retaliation to the Title IX Coordinator at campus or Deputy Title IX Coordinator for JPL, as applicable.

An individual who has experienced sexual misconduct is encouraged to immediately seek assistance from a medical provider and report the incident to local law enforcement, which the confidential Campus Sexual Violence Advocate can coordinate and facilitate. Reports to Caltech and law enforcement may be pursued simultaneously.

If a member of the Caltech community would like support and guidance in reporting Prohibited Conduct, they may contact the Title IX Coordinator or a deputy coordinator, one of the deans or associate deans, the director of employee and organizational development in Human Resources, or the JPL section manager of talent management or Human Resources Business Partners at JPL. They may also contact any of the EEO coordinators identified in the Nondiscrimination and Equal Employment Opportunity Policy.

6.1 Title IX Coordinator

The Title IX Coordinator is responsible for coordinating Caltech's compliance with Title IX and for Caltech's overall response to Prohibited Conduct falling under Title IX. The Title IX Coordinator oversees the implementation and application of this policy and the related procedures to ensure the prompt and equitable resolution of complaints and the consistent treatment of the parties involved. The names and contact information for the Title IX Coordinator and Deputy Title IX Coordinators are provided in the Procedures for Complaints of Sexual Misconduct Under Title IX and the California Education Code.

6.2 Responsible Employees

A Responsible Employee is broadly defined to mean an employee who has the authority to take action to redress sexual harassment or provide supportive measures to students, or who has the duty to report sexual harassment to an appropriate school official who has that authority.

If an individual discloses Prohibited Conduct to any Responsible Employee, or if a Responsible Employee through any person or means, whether directly or indirectly, becomes aware of Prohibited Conduct (as defined below in III: Prohibited Conduct, Sections 13.0 and 14.0), they must report to the Title IX Coordinator all relevant details about the alleged conduct.

At Campus, Responsible Employees include but are not limited to:

- Title IX Coordinator, deputy coordinators for faculty, students, and staff, and associated staff in the Equity and Title IX Office
- All faculty members, teachers, instructors, and lecturers
- All deans and associate deans
- All Housing and Student Affairs directors and coordinators, including Residential Life Coordinators
- Resident Associates while performing the duties of employment
- Staff members with a supervisory or managerial role, whom Caltech has not designated as confidential resources
- Security officers
- All Athletics directors, coordinators, and coaches at all levels
- Employee Relations consultants
- Coaches of any student athletic or academic team or activity (e.g., employees who are club advisors, music coaches, etc.)
- Graduate student instructors, while performing the duties of employment
- Laboratory directors, coordinators, or principal investigators

- Internship or externship directors or coordinators
- Study-abroad program directors or coordinators

At Campus, the term Responsible Employee does not include Confidential Resources, including the licensed therapists in the Staff and Faculty Consultation Center and the Student Wellness Counseling Services, and the Campus Sexual Violence Advocate. These individuals are not required to report Prohibited Conduct to the Title IX Coordinator unless required by law to do so. However, these individuals shall inform anyone who provides them with information regarding sexual harassment of their ability to report to Responsible Employees and direct them to those reporting resources. Confidential Resources on Campus include:

Student Wellness Services Counseling
1239 Arden Road
626-395-8331
Staff and Faculty Consultation Center
315 So. Hill Avenue
626-395-8360
Campus Sexual Violence Advocate
Center for Student Services, Room 168
626-395-4770
At JPL, the following are Responsible Employees:

- Deputy Title IX Coordinator for JPL and associated staff
- Supervisors and managers
- Employee Relations representatives
- Education Office staff
- Chief Scientist Office staff

At JPL, the term "Responsible Employee" does not include licensed therapists in JPL's Employee Assistance Program provided through Empathia.

6.3 Anonymous Reporting
A report is considered anonymous if the reporting party does not share their name or contact information. If a reporting party chooses to provide their name or contact information, the report will not be considered anonymous, and, if applicable, they will receive information about support resources, reporting options, and notification of an investigation, if an investigation is pursued.

Caltech provides the following resources for anonymous reporting:
Caltech Hotline (626) 395-8787 or (888) 395-8787
JPL Ethics Hotline (818) 354-9999
JPL Protective Services Division's Workplace Violence Hotline (818) 393-2851
For either Campus or JPL, by submitting a compliance Hotline Contact Form
A reporting party may also use the Report Form on the Equity and Title IX Office website, which can be submitted anonymously by not filling in the contact information.

6.4 Notifications of Law Enforcement as Required by California Law
Individuals who have experienced sexual assault, stalking, sexual exploitation, or domestic relationship, or dating violence are encouraged to notify local law enforcement. Caltech will provide assistance in notifying law enforcement if the individual so chooses. If the complainant chooses to notify law enforcement, they may seek the assistance of the Equity and Title IX Office. The Equity and Title IX Office is available to facilitate the contact with law enforcement and the scheduling of a meeting, if the complainant chooses to make a report. An individual who has experienced sexual violence also has the right to decline to notify law enforcement or Caltech.

Caltech makes the following mandated reports of sexual misconduct to law enforcement: (a) incidents of sexual assault or sexual battery of a minor, as defined by California law; and (b) summary reports of incidents of sexual assault or sexual battery, under California Education Code Section 67383); however, Caltech will not report identifying information about the complainant without the complainant's consent after being notified of their right to have personally identifying information withheld. If the complainant does not consent to be identified, personally identifying information about the respondent also will not be provided.

Individuals may also engage with the confidential Campus Sexual Violence Advocate who can facilitate a report to law enforcement.

Pasadena Police Department
Call 911 for Emergency Response
Non-Emergency Response: (626) 744-4241
207 N. Garfield Ave., Pasadena, CA 91101

6.5 Amnesty Policy for Students
A student who participates as a complainant or witness in an investigation of sexual assault, dating violence, domestic violence, or stalking will not be subject to disciplinary sanctions for a violation of Caltech's student conduct policies at or near the time of the incident, including but not limited to the Substance Abuse policy, unless Caltech determines that the violation was egregious. Egregious violations include but are not limited to an action that places the health or safety of any other person at risk or involves conduct that violates Caltech's policies prohibiting discrimination or other serious misconduct like plagiarism, cheating, research misconduct, or other forms of academic dishonesty. Employee amnesty is at the discretion of the Title IX Coordinator and Employee Organizational Development.

7.0 Reports Involving Minors
Every member of the Caltech community who knows of or reasonably suspects child abuse or neglect, including any Prohibited Conduct involving a minor, has a personal responsibility to report the suspected child abuse or neglect to Caltech Security or the JPL Protective Services Division immediately.

Caltech employees who are mandated reporters have additional, legally required reporting obligations, including reporting immediately to the LA County Office of Child Protection and/or the local police

department. See Mandated Reporter Guidelines and the Violence Prevention Policy for more information.

8.0 False Reports/Statements

Caltech expects its members to act with honesty, sincerity, and good faith in reporting concerns under this policy. Caltech will not tolerate intentional false reporting of information, allegations, or evidence. A good faith complaint that is not substantiated by a preponderance of the evidence after an investigation is not considered a false report.

However, when a complainant or third party is found to have intentionally fabricated or knowingly misrepresented information, allegations, or evidence, or otherwise to have acted with an intent to deceive or mislead in any of their dealings relating to Caltech's administration of this policy, they may be subject to disciplinary action up to and including termination of employment, student expulsion, or being permanently excluded from Caltech-controlled premises.

9.0 Privacy

Caltech will maintain the privacy of all individuals involved in a report of Prohibited Conduct to the extent practicable. Throughout the process, every effort is made, at the discretion of the Title IX Coordinator, to protect the privacy interests of all individuals involved in a manner consistent with the need for a thorough review and administration of the matter.

No meetings or conversations that take place under this policy, the Procedures for Complaints of Sexual Misconduct, or the Procedures for Complaints of Unlawful Discrimination, Harassment, and Retaliation may be audio- or visually recorded by anyone. The only exception to this rule is that the Equity and Title IX Office, in compliance with Title IX, will record hearings conducted under the Title IX Complaint Procedures in order to provide a verbatim record of the hearing. These recordings will be maintained by the Equity and Title IX Office.

10.0 Contacting Government Agencies

Filing a complaint with a federal agency under Title IX must be done within 180 days of an alleged discriminatory or harassing event, and there is no requirement to exhaust remedies through (i.e., utilize or go through) Caltech's internal procedures before filing directly with a federal agency.

Employees, students, and others participating in Caltech's educational programs or activities may direct questions regarding Title IX to or file complaints with the U.S. Department of Education Office for Civil Rights, (202) 607-1600, ocr.seattle@ed.gov, or (800) 421-3481, OCR@ed.gov. In addition, employees may file complaints with the California Civil Rights Department at dfeh.ca.gov/contact-us or the United States Equal Employment Opportunity Commission (EEOC) at eeoc.gov. Complaints can also be directed to the Bureau for Private Postsecondary Education at bppe.ca.gov.

NASA-funded program participants may file a complaint at

AssistedProgramComplaint@nasa.gov or find more information at missionstem.nasa.gov/filing-a-complaint.html. NSF-funded program participants may file a complaint with the Office of Diversity and Inclusion at programcomplaints@nsf.gov, (703) 292-8020, or find more information at nsf.gov/od/odi/harassment.jsp. Participants in programs funded by other federal agencies providing federal financial assistance to Caltech may file directly with those agencies.

11.0 Clery Reporting

The federal Clery Act requires Caltech to issue an Annual Security and Fire Safety Report, which includes crime statistics for sexual assault (rape, and criminal sexual contact, incest, and statutory rape), domestic violence, dating violence, and stalking. Campus Security gathers these crime statistics from the Equity and Title IX Office, security reports, Pasadena Police Department information, JPL, and reports by Campus Security authorities. Crime statistics do not disclose any identifying information about the complainant, respondent, witnesses, or others and do not disclose any details of the incident. For more information and statistics for the past three years, see the current Annual Security and Fire Safety Report.

SECTION III: PROHIBITED CONDUCT

12.0 Scope

This section sets out what conduct is Prohibited Conduct under this policy. For clarity, transparency, and administrative ease, this Section delineates sexual harassment prohibited under the federal Title IX regulations (Section 13.0) and under the California Education Code (Section 14.0). Additional misconduct prohibited by Caltech and other applicable law, including attempts and threats of Prohibited Conduct, is described in Section 15.0.

Reported behavior that does not constitute Prohibited Conduct under this policy but is nevertheless determined to be inappropriate pursuant to another applicable Caltech policy, such as the Unlawful Harassment and Abusive Conduct Policy, and may subject the offending individual to disciplinary action.

The Title IX Coordinator will determine whether reported Prohibited Conduct is covered under the sexual harassment provisions of Title IX or constitutes other Prohibited Conduct as described under this policy and will apply the appropriate procedures. Allegations of Title IX-covered (Section 13.0) and California Education Code-covered (Section 14.0) Prohibited Conduct will be addressed under the Procedures for Complaints of Sexual Misconduct ("Procedures"). Where multiple allegations of Prohibited Conduct are at issue, and the Title IX Coordinator determines that only a portion falls within the scope of Sections 13.0 and 14.0, all the allegations will be adjudicated under the Procedures for Complaints of Sexual Misconduct. Allegations of Prohibited Conduct falling exclusively under Section 15.0 will be addressed under Caltech's Procedures for Complaints of Unlawful Discrimination, Harassment, and Retaliation.

13.0 Sexual Misconduct under Title IX

Title IX prohibits sexual harassment if it meets the definitions set out in this section.

13.1 Definition of Sexual Harassment under Title IX

Sexual harassment means conduct, on the basis of sex, that satisfies one or more of the following: (1) an employee of Caltech conditioning the provision of an aid, benefit, or service of Caltech on an individual's participation in unwelcome sexual conduct; (2) unwelcome conduct determined by a reasonable person to be so severe, pervasive, and objectively offensive that it effectively denies a person equal access to Caltech's education program or activity; or (3) sexual assault, dating violence, domestic violence, or stalking, as defined below.

13.1.1 Sexual Assault

Sexual assault means an offense classified as a sex offense under the uniform crime reporting system of the Federal Bureau of Investigation, as follows:

Any sexual act directed against another person without the consent of the victim, including instances where the victim is incapable of giving consent.

***Rape*:** Penetration, no matter how slight, of the vagina or anus with any body part or object, or oral penetration by a sex organ of another person, or by a sex-related object, without the affirmative consent of the victim. This definition includes instances in which the victim is incapable of giving consent because of temporary or permanent mental or physical incapacity (including due to the influence of drugs or alcohol) or because of age. Physical resistance is not required on the part of the victim to demonstrate lack of consent. This definition excludes statutory rape.

***Criminal Sexual Contact*:** The intentional touching of the clothed or unclothed body parts without consent of the victim for the purpose of sexual degradation, sexual gratification, or sexual humiliation. The forced touching by the victim of the actor's clothed or unclothed body parts, without consent of the victim for the purpose of sexual degradation, sexual gratification, or sexual humiliation.

***Incest*:** Sexual intercourse between persons who are related to each other within the degrees wherein marriage is prohibited by law.

***Statutory Rape*:** Sexual intercourse with a person who is under the statutory age of consent, which in California is 18.

13.1.2 Dating and Domestic Violence

Dating violence means violence committed by a person who is or has been in a social relationship of a romantic or intimate nature with a complainant. The existence of such a relationship shall be determined based on the complainant's statement as well as consideration of the length of the relationship, the type of relationship, and the frequency of interaction between the persons involved in the relationship. Dating Violence includes, but is not limited to, sexual or physical abuse or the threat of such abuse. Dating Violence does not include acts covered under the definition of Domestic Violence.

Domestic violence means conduct, on the basis of sex, that constitutes a felony or misdemeanor crime of violence committed upon a victim who is (a) the offender's spouse or former spouse, (b) the offender's cohabitant or former cohabitant; or (c) the offender's fiancé or fiancée, or someone with whom the offender has, or previously had, an engagement or dating relationship; (d) the parent of the offender's child; or (e) any other victim who is protected under the domestic or family violence laws of the state where the domestic violence occurred.

13.1.3 Stalking

Stalking means engaging in a course of conduct directed at a specific person that would cause a reasonable person to fear for his or her safety or the safety of others; or suffer substantial emotional distress.

"Course of conduct" means two or more acts, including, but not limited to, acts in which the stalker directly, indirectly, or through third parties, by any action, method, device, or means, follows, monitors, observes, surveils, threatens, or communicates to or about a person, or interferes with the person's property. Making an audio or video recording of an individual without their consent is prohibited and may constitute stalking under this policy or the Violence Prevention Policy.

"Reasonable person" means a reasonable person under similar circumstances and with similar legally protected or other characteristics to the victim.

Stalking is also covered by the Violence Prevention policy and should be reported to the Equity and Title IX Office and Security at campus or the Protective Services Office at JPL.

13.2 Additional Requirements for Title IX Sexual Harassment

Title IX addresses sexual harassment in an education program or activity of Caltech against a person in the United States.

At the time of filing a formal complaint, a complainant must be participating in or attempting to participate in an education program or activity of Caltech. The term "attempting to participate" includes when a complainant has: (a) applied for admission; (b) graduated but intends to apply for a new program; (c) graduated but intends to participate in alumni programs and activities; (d) gone on leave but is still enrolled; (e) gone on leave but intends to re-apply after the leave; (f) withdrawn due to alleged sexual harassment and expresses a desire to re-enroll if Caltech responds appropriately to the allegations.

The term "education program or activity" includes buildings or other locations that are part of the school's operations, including remote learning platforms; (a) locations, events, or circumstances, even if off-campus, over which Caltech exercised substantial control over both the respondent and the context in which the alleged sexual harassment occurred; and (b) any building, even if off-campus, owned or controlled by a student organization that is officially recognized by Caltech.

13.3 Limitation on Claiming Conduct as a Defense to Sexual Harassment

When a consensual personal relationship arises and a power differential exists, Caltech does not consider consent as a defense to a claim of sexual harassment. The individual in the relationship with greater power will be held responsible.

14.0 Sexual Misconduct under the California Education Code

The California Education Code (CEC) prohibits sexual harassment if it meets any of the definitions of sexual assault, dating violence, domestic violence, and stalking under Section 13.0, and sexual harassment set out below in this section.

14.1 Definition of Sexual Harassment under the CEC

Sexual harassment means unwelcome sexual advances, requests for sexual favors, and other verbal, visual, or physical conduct of a sexual nature, [1]made by someone from or in the work or educational setting, under any of the following conditions:

Submission to the conduct is explicitly or implicitly made a term or a condition of an individual's employment, academic status, or progress.

Submission to, or rejection of, the conduct by the individual is used as the basis of employment or academic decisions affecting the individual.

The conduct has the purpose or effect of having a negative impact upon the individual's work or academic performance, or of creating an intimidating, hostile, or offensive work or educational environment.

Submission to, or rejection of, the conduct by the individual is used as the basis for any decision affecting the individual regarding benefits and services, honors, programs, or activities available at or through the educational institution.

Sexual violence, which means physical sexual acts perpetrated against a person without the person's affirmative consent, including rape and sexual battery.

Rape, which is defined as penetration, no matter how slight, of the vagina or anus with any part or object, or oral copulation of a sex organ by another person, without the consent of the victim.

Sexual battery, which means the (a) intentional touching, directly or through clothing, of another person's intimate parts without consent, (b) intentionally causing a person to touch the intimate parts of another, directly or through clothing, without consent, or (c) using a person's own intimate part to intentionally touch another person's body, directly or through clothing, without consent. "Intimate body" parts are the breast, genitals, groin, anus, or buttocks.

Sexual exploitation, which means a person taking sexual advantage of another person for the benefit of anyone other than that person without that person's consent, including, but not limited to, any of the following acts:

- The prostituting of another person.

- The trafficking of another person, defined as the inducement of a person to perform a commercial sex act, or labor or services, through force, fraud, or coercion.
- The recording of images, including video or photograph, or audio of another person's sexual activity or intimate parts, without that person's consent.
- The distribution of images, including video or photograph, or audio of another person's sexual activity or intimate parts, if the individual distributing the images or audio knows or should have known that the person depicted in the images or audio did not consent to the disclosure.
- The viewing of another person's sexual activity or intimate parts, in a place where that other person would have a reasonable expectation of privacy, without that person's consent, for the purpose of arousing or gratifying sexual desire.

1 "Verbal" sexual harassment includes but is not limited to unwelcome epithets, comments, or slurs of a sexual nature. "Visual" sexual harassment includes but is not limited to derogatory posters, cartoons, drawings, obscene gestures, or computer-generated images of a sexual nature. "Physical" sexual harassment includes but is not limited to assault, impeding or blocking movement, or any other physical interference with work or academic activities or movement when directed against an individual on the basis of sex.

14.2 Limitation on Claiming Consent as a Defense to Sexual Harassment

When a consensual personal relationship arises and a power differential exists, Caltech does not consider consent as a defense to a claim of sexual harassment. The individual in the relationship with greater power will be held responsible.

15.0 Additional Conduct Prohibited by Caltech

This section describes additional misconduct prohibited by Caltech and under applicable law, but that is not subject to the Procedures for Complaints of Sexual Misconduct. Complaints of such Prohibited Conduct will be addressed under the Procedures for Complaints of Unlawful Discrimination, Harassment, and Retaliation.

15.1 Complicity

Complicity is any act that knowingly aids, facilitates, promotes, or encourages the commission of Prohibited Conduct by another person.

15.2 Violation of a Caltech Directive

Any individual may be found in violation for failure to comply with a Caltech directive regarding a supportive measure (e.g., violating the terms of a Mutual No-Contact Order).

15.3 Prohibition on Sex Discrimination

Sex- and Gender-Based Discrimination constitutes Prohibited Conduct under this policy.

Sex discrimination under Title IX occurs when a person in the United States, on the basis of actual or perceived sex, is excluded from participation in, or is denied the benefits of, or is subjected to discrimination, under any Caltech education program or activity. The term "education program or activity" encompasses all of the operations of Caltech.

Sex discrimination also includes unfavorable treatment on the basis of sex, gender, gender identity, gender expression, and sexual orientation.

Gender expression means a person's gender-related appearance and behavior, whether or not stereotypically associated with the person's assigned sex at birth.

15.4 Prohibition on Sex Harassment

Sex-based and gender-based harassment is harassment based on an individual's actual or perceived sex, gender, gender identity, or gender expression, including harassing or bullying conduct based on the individual's gender expression, gender identity, transgender status, gender transition, or nonconformity with sex stereotypes.

15.5 Prohibition on Relationships between Employees and Undergraduates

This policy prohibits sexual or romantic relationships between an undergraduate student and a faculty member, postdoctoral scholar, or staff member. Any Responsible Employee who becomes aware of such a relationship is expected to report it immediately to the Title IX Coordinator. The non-undergraduate party in the relationship will be held responsible for Prohibited Conduct violating this policy, regardless of whether a complaint is filed.

15.6 Prohibition on Evaluative Responsibilities in Certain Circumstances

Even when relationships are consensual, care must be taken to eliminate the potential for harassment or other conflicts. Caltech practice, as well as more general ethical principles, prohibits individuals, including Teaching Assistants, from participating in evaluating the work or academic performance of those with whom they have romantic and/or sexual relationships, or from making hiring, salary, or similar decisions regarding those individuals. Upon learning about a consensual relationship involving such a power differential, the supervisor, dean, or division chair should immediately notify the Title IX Coordinator and, in consultation with the Title IX Coordinator, should review and remedy any direct administrative or academic relationship between the involved individuals. The individual with greater power may be subject to disciplinary action for a violation of this prohibition.

15.7 Prohibition on Inequitable Treatment Stemming from Consensual Relationships

Even when relationships are consensual, care must be taken to eliminate the potential for harassment or other conflicts. If a consensual relationship exists, it is not acceptable to treat the individual in the relationship more favorably than other similarly situated individuals in the context of employment or academic performance.

15.8 Prohibition on Uncompleted Attempts or Threats of Prohibited Conduct

To the extent that uncompleted attempts or threats of Prohibited Conduct are not covered in Sections 13.0 and 14.0 of this policy, they are covered in Section 15.0. Threats of Prohibited Conduct may also constitute retaliation under this policy.

15.9 General Caution about Maintaining Appropriate Professional Boundaries

All members of the Caltech community should maintain respectful and professional boundaries with one another. This is particularly important when Caltech employees, whether faculty, postdoctoral scholars, or staff, interact with their subordinates, or with graduate and undergraduate students, due to the power differential that exists between them.

While certain conduct may not constitute Prohibited Conduct, it can create situations where students or others feel uncomfortable but reluctant to voice that sentiment.

Depending on the circumstances, such situations may include hosting students at private homes, sharing lodging on academic-related trips (e.g., conferences, field trips), wearing swimsuits (e.g., marine research outing), and any interaction where alcohol is consumed (e.g., dinners at conferences, field trips, holiday parties).

Caltech encourages employees and other community members to think carefully about maintaining appropriate professional boundaries at all times, to state their boundaries as appropriate, and to consider seeking guidance from the Title IX Coordinator.

16.0 Affirmative Consent

Consent is a key component of various definitions of Prohibited Conduct. Affirmative consent is the standard of consent in Caltech's policy. A minor under the age of eighteen (18) is deemed to be incapable of providing affirmative consent under this policy. Affirmative consent is the affirmative, conscious, and voluntary agreement to engage in sexual activity.

- It is the responsibility of each person involved in the sexual activity to ensure that they have the affirmative consent of the other person(s) to engage in the sexual activity.
- Lack of protest or resistance does not mean consent, nor does silence mean consent.

- Affirmative consent must be ongoing throughout a sexual activity and each time sexual activity is engaged in, and it can be revoked at any time. Sexual contact must cease immediately once consent is withdrawn and clearly communicated. Consent to one form of sexual activity is not, by itself, consent to other forms of sexual activity.
- The existence of a dating relationship between the persons involved, or the fact of any past sexual activity between them, should never by itself be assumed to be an indicator of consent.

It is not a valid excuse in response to an alleged lack of affirmative consent that the respondent believed that the complainant consented to the sexual activity under either of the following circumstances:

- The respondent's belief in affirmative consent arose from the intoxication or recklessness of the respondent.
- The respondent did not take reasonable steps, in the circumstances known to the respondent at the time, to ascertain whether the complainant affirmatively consented.

It is not a valid excuse that the respondent believed that the complainant affirmatively consented to the sexual activity if the respondent knew or reasonably should have known that the complainant was unable to consent to the sexual activity under any of the following circumstances:

- The complainant was asleep or unconscious.
- The complainant was incapacitated due to the influence of drugs, alcohol, medication, or otherwise (such as a temporary or permanent mental or physical condition), such that the complainant could not understand the fact, nature, or extent of the sexual activity. A person who is incapacitated is not capable of giving effective consent to sexual activity. In evaluating affirmative consent in cases involving an allegation of incapacitation, Caltech considers the state and degree of intoxication of the reporting party and the knowledge of the respondent.
- The complainant was unable to communicate due to a mental or physical condition.

One's own intoxication, even to the point of incapacitation, does not relieve an individual from responsibility for a policy violation when they engage in sexual conduct without the affirmative consent of the other party or parties. However, a respondent who was incapacitated during sexual conduct has the right to file a formal complaint alleging they were incapacitated and unable to consent to the reported sexual activity.

17.0 Informational Resources

Information on Prohibited Conduct, as well as copies of Caltech's Sex Discrimination; Nondiscrimination and Equal Employment Opportunity; Unlawful Harassment; and Violence Prevention policies are available from the following resources:

At Campus: Caltech's Title IX Coordinator and deputy Title IX Coordinators, Caltech's EO Coordinators, Human Resources, Student Affairs, the Deans' Offices, the Caltech Center for Inclusion and Diversity, Resident Associates, the Staff and Faculty Consultation Center, and Employee and Organizational Development.

At JPL: JPL's deputy Title IX Coordinator, EO Coordinator, and Human Resources Business Partners.

The policies are published in the Caltech Catalog and on the following Caltech and JPL websites: JPL Human Resources, Equity and Title IX Office, and Student Affairs.

PROCEDURES FOR COMPLAINTS OF SEX DISCRIMINATION

I. Introduction

Caltech's Sex Discrimination Policy ("Policy") reflects Caltech's commitment to support and encourage individuals who have been subjected to Prohibited Conduct to come forward. Caltech takes all allegations of Prohibited Conduct seriously and responds appropriately.

Caltech's Policy and these Sex Discrimination Procedures ("Procedures") are intended to ensure that individuals accused of engaging in Prohibited Conduct are not prejudged; that they have notice and a full and fair opportunity to respond to allegations before findings and conclusions are reached; and that decisions are based on the evidence gathered in a process that is fair to both complainants and respondents when an investigation is conducted.

The Sex Discrimination Policy and these Sex Discrimination Procedures, including information on where and how reports and complaints may be filed, is provided to all Caltech students on the Equity and Title IX Office website on the Resources page as well as by email at the start of the academic year.

II. Procedure Scope and Applicability

These Procedures are to be applied, when both parties are "covered persons," to address allegations of Prohibited Conduct that (a) fall within the scope set out in Section I, 2.0, of the Sex Discrimination Policy, *and* (b) fall within the definitions of sexual harassment, as defined by Title IX and/or the California Education Code and set out in Sections 13.0 or 14.0, respectively, of the Sex Discrimination Policy. All other Prohibited Conduct under the Policy is addressed under the Procedures for Unlawful Discrimination, Harassment and Retaliation. The Title IX Coordinator determines whether these Procedures apply.

Throughout these Procedures, any reference to a Caltech or JPL administrator is understood to include not only that administrator but also their designee.

III. Time Frames
These Procedures set out below reasonably prompt time frames for major procedural stages. The Title IX Coordinator, at their own discretion or upon the request of a party or witness, may extend a time frame for good cause, providing prompt written notice to the parties of any delays or extensions and the reasons therefor.

- "Good cause" may include but is not limited to the absence of a party, a party's advisor, or a witness; concurrent law enforcement activity; the need for language assistance or accommodation of disabilities; the breadth and scope of the allegations, e.g., in terms of content and date, the number of potential witnesses, and the amount of available, relevant documentary evidence; the need to conduct a thorough, fair, and accurate investigation; and office closures.
- Parties must communicate requests for extensions to the Title IX Coordinator before deadlines have passed, to the extent practicable.
- Where an individual asks for adjustments to timelines based on an accommodation of
  a medical condition or disability, they will be required to follow the applicable Institute disability accommodation process in requesting an accommodation, as described in the Institute Disability and Reasonable Accommodation Policy or appropriate student accessibility services process. Requests for extensions may be denied where individuals fail to meet deadlines established during the accommodations process.

The Title IX Coordinator shall not unreasonably deny a party's request for an extension of a deadline related to a complaint during periods of examinations or school closures.

IV. Initial Title IX Assessment and Outreach
Within 10 (ten) business days of receiving a report of Prohibited Conduct, Caltech's Title IX Coordinator will make an initial assessment of the report to determine the following:

1. A reasonable assessment of any safety concerns posed to any member of the Caltech community or Caltech's campus;
2. Whether the allegations on their face present a potential violation of the Sex Discrimination Policy; and if so, whether they are covered under these Procedures or under Caltech's Procedures for Unlawful Harassment and Abusive Conduct; or, if not, whether they should be addressed under a different Caltech policy and process;
3. Whether and what supportive measures are warranted; and
4. Whether emergency removal is warranted.

Outreach to Parties. The Title IX Coordinator will promptly reach out (in writing, to the extent appropriate) to each identifiable complainant or alleged victim of the report to inform them, as

appropriate, of the receipt of the report, discuss the availability of supportive measures, consider their wishes with respect to supportive measures, inform them that supportive measures are available with or without the filing of a formal complaint, and explain to them the process for filing a formal complaint and the importance of preserving evidence and identifying witnesses and their contact information.

The Title IX Coordinator's outreach will also include a statement that retaliation for filing a complaint or participating in a resolution process, or both, is prohibited by Caltech policy and federal and California law. The Title IX Coordinator will provide them with a copy of these Sex Discrimination Procedures. Where a crime may have occurred, the Title IX Coordinator will provide the complainant or alleged victim notice of their right to report the matter to law enforcement and information on how Caltech can help facilitate such reporting. The Title IX Coordinator will also describe how Caltech responds to reports of Prohibited Conduct, as well as potential disciplinary consequences. The Title IX Coordinator will refer them to and help coordinate, if desired, support resources, including providing information on the availability of and contact information for on-campus and off-campus resources and services. Finally, the Title IX Coordinator will request for the complainant or alleged victim to meet with them to discuss options for responding to the report.

The Title IX Coordinator may also meet with the respondent and other relevant individuals in order to make an initial assessment. The respondent will be offered the opportunity to request and receive supportive measures at this time.

Information Provided to Both Parties. Both the complainant and the respondent will be provided with the following:

1. Information on their rights and options under the Sex Discrimination or Unlawful Harassment policies and related procedures as appropriate, and copies of these documents;
2. Written materials outlining information on on-campus and off-campus support resources and services, including contact information and days and hours of availability, as well as information on coordination with law enforcement;
3. Information on the importance of policy concerning evidence preservation;
4. Information on the policy against retaliation for filing a complaint or participating in a complaint process.

V. Advisor

The complainant and respondent may have either an advisor or a support person (hereinafter, collectively, "advisor") of their choice (other than a witness or their direct supervisor or other member of their line management), including a victim advocate or an attorney, accompany and generally support them at any virtual or live meetings or phone calls at any point in the procedures discussed below. However, Caltech resolution processes, including the investigation process, are not legal proceedings and the advisor may not speak or submit written statements on behalf of the individual they are advising

(other than at the hearing, if any), Caltech will not be responsible for communicating information to advisors, or scheduling meetings around advisors' availability. Advisors are required to sign and abide by Caltech's Advisor Policy setting forth the parameters of their role.

Advisor's Role. The role of the advisor is to (a) provide general support to a party participating in any step of the processes outlined below, (b) encourage the party whom the advisor supports to communicate for themself, and (c) respect the process and procedures. All communications, whether oral or written, will be between the Equity and Title IX Office staff member(s), investigator(s), or other appropriate participating administrator(s), or their designees, ("Title IX process administrators"), and the party only. The advisor may not speak during any meeting, including on behalf of the party whom they support, ask questions of the administrator(s) or of the party whom they support, or otherwise interfere with or disrupt the meeting, conversation, or procedure. Nor may an advisor communicate on behalf of the party in emails or other correspondence with the Equity and Title IX Office. However, during meetings, the advisor may provide written notes or instructions to the party whom they support.

All parties have the right to consult with an attorney at their own expense, at any procedural step set forth below, if they wish to do so. An attorney may serve, but is not required to serve, as an advisor.

Caltech is not required to identify or provide advisors to parties, except in investigations requiring a hearing.

VI. Supportive Measures

Supportive measures are non-disciplinary, nonpunitive individualized services offered as appropriate and reasonably available to the parties before or after the filing of a formal complaint or where no formal complaint has been made or no investigation has been undertaken. Supportive measures are available to parties regardless of whether they participate in a resolution process. They are designed to restore or preserve equal access to Caltech's education program or activity without unreasonably burdening the other party, including measures designed to protect the safety of all parties or Caltech's educational environment, or to deter Prohibited Conduct. Caltech will consider and respond to requests for accommodations relating to prior incidents of sexual harassment that could contribute to a hostile educational environment or otherwise interfere with a student's access to education where both individuals are, at the time of the request, subject to Caltech's policies.

All parties are expected to comply with any supportive measures that may be imposed. Failure to comply with supportive measures may be grounds for disciplinary action under Caltech policies, even if the noncomplying party is found not responsible for the underlying report of Prohibited Conduct.

The imposition of supportive measures is not indicative of a determination of responsibility or any other outcome. These measures may be modified at any time and may be kept in place after a final investigative decision is reached.

Forms of Supportive Measures. Supportive measures may include counseling, academic accommodations (e.g., extensions of deadlines, course-related adjustments), modifications of work or class schedules, campus escort services, mutual restrictions on contact between the parties, including in a virtual or electronic environment, changes in work or housing locations, leaves of absence, increased security and monitoring of certain areas of campus, referrals to campus and off-campus support resources, and other similar measures.

Confidentiality. Caltech will maintain as confidential any supportive measures provided to any party to the extent such confidentiality does not impair Caltech's ability to provide the supportive measures (e.g., notifying appropriate administrators involved in academic accommodations).

Academic Accommodations. The Title IX Coordinator will coordinate the effective implementation of supportive measures. Academic accommodations should be requested in a timely manner, reasonably in advance of deadlines. Retroactive accommodations, such as re-taking tests or extensions after the due date has passed, will not be granted. Supportive measures affecting faculty, postdoctoral scholars, and staff, including employees at JPL, might include transfer of supervisory or evaluative responsibility regarding grading, supervision, tenure review, letters of recommendation, and/or changes to office assignments.

No Contact Orders. When requested by a party or otherwise determined to be appropriate, Caltech will issue a mutual no-contact order. Caltech will not issue such an order automatically but instead shall consider the specific circumstances of each case to determine whether the order is necessary or justifiable to protect the non-complaining party's safety or well-being, or to respond to interference with a resolution process. Upon the issuance of a mutual no-contact order, Caltech will provide the parties with a written justification for the order, an explanation of its terms, and the circumstances, if any, under which violation could be subject to disciplinary action. If a party wishes to seek a temporary restraining order or similar judicial order, Caltech will help the party with that process. Parties may seek the assistance of the Campus Sexual Violence Advocate.

VII. Retaliation

Retaliation against any member of the Caltech community at any point in time for making a good-faith report of Prohibited Conduct or participating or refusing to participate in any manner in an investigation, proceeding, or hearing conducted by Caltech or a state or federal agency, is strictly prohibited. Allegations of retaliation that are alleged at the time of a formal complaint of sexual harassment, as defined in policy Sections 13.0 and 14.0, will be addressed as part of that complaint.

Complaints of retaliation that are not alleged at the time of a sexual harassment complaint may be addressed under the Procedures for Complaints of Unlawful Discrimination, Harassment and Retaliation. The Title IX Coordinator will have the ultimate discretion over which

procedures apply to a claim of retaliation.

VIII. Emergency Removal

The Title IX Coordinator will undertake an individualized safety and risk analysis for the purpose of determining whether the respondent, based on the alleged conduct, is an immediate, imminent threat to the physical health or safety of any student or other individual, justifying their removal from campus or other appropriate scope of removal. The Title IX Coordinator may consult with any individuals they consider pertinent and appropriate to making the emergency removal determination. The safety and risk factors that the Title IX Coordinator will consider include but are not limited to the nature of the allegations, the alleged number and age(s) of the complainant(s), the power differential between the respondent and complainant(s), whether the respondent is alleged to have used a weapon, violence, drugs, or alcohol to intimidate, harm, or control a complainant, and whether the allegations present a pattern of behavior or otherwise suggest a likelihood of repeated misconduct.

Caltech may also place nonstudent employee respondents on administrative leave while a complaint resolution process is pending.

Appeal of Removal Decision. Where the Title IX Coordinator has determined that emergency removal of a student respondent is appropriate, the respondent will be provided with notice and an opportunity to challenge the decision immediately following the removal. To challenge a removal decision by the Title IX Coordinator, the respondent must submit a written appeal to the associate vice president for human resources within seven (7) business days of receipt of notice. In deciding this appeal, the associate vice president for human resources may consult with any individuals they consider pertinent and appropriate to making the decision. The decision of the associate vice president for human resources is final. **Duration of Removal.** A student who has been subject to an emergency removal may not return to campus until the emergency removal has been lifted. Prior to the beginning of a new term, an individual who has been subject to emergency removal may request that the Title IX Coordinator reconsider the scope or continuation of their removal.

IX. Complainant's Request for Confidentiality or No Further Action

With respect to allegations of Prohibited Conduct under the Sex Discrimination Policy, the Title IX Coordinator makes every effort to respect the complainant's capacity to make independent choices regarding resolution options for addressing their complaints under the Policy and these Procedures.

In instances where a complainant requests that their name not be used, Caltech will seriously consider the request but weigh the request against Caltech's duty to provide a safe, nonthreatening, and nondiscriminatory environment for all community members including its responsibilities under applicable laws. Similarly, where the complainant requests that the complaint not be pursued (including an investigation) or that no disciplinary action be taken, Caltech will seriously consider the request but weigh the request against Caltech's

duty to provide a safe, nonthreatening, and nondiscriminatory environment for all community members including its responsibilities under applicable laws. The Title IX Coordinator will discuss with the complainant the reasons for their requests and attempt to address the underlying concerns, such as taking steps to prevent retaliation.

Where the complainant remains committed to the request that their name not be used or the complaint not be pursued, and the alleged Prohibited Conduct falls under Title IX Sexual Misconduct (policy Section 13.0), the Title IX Coordinator has the discretion to proceed with the investigation, including potentially disclosing the complainant's name to protect the health and safety of the complainant and the Caltech community. In making such a determination, the Title IX Coordinator will weigh the complainant's request against relevant factors, including but not limited to:

- the nature and seriousness of the alleged conduct;
- whether the allegations are contested;
- the involvement of multiple respondents;
- the existence of multiple or prior reports of misconduct against the respondent;
- whether there was a weapon, physical restraints, battery, or other violence involved;
- whether the use of alcohol or drugs to induce vulnerability to sexual activity without consent was allegedly involved;
- whether there is evidence of a pattern of conduct;
- the presence of other circumstances that suggest there is a significant risk that the respondent will commit further acts of Prohibited Conduct;
- the age of a complainant;
- whether the respondent is a faculty or staff member with oversight of students;
- whether there is a power imbalance between the complainant and respondent;
- whether the complainant believes that the complainant will be less safe if the complainant's name is disclosed or an investigation is conducted; and
- whether Caltech is able to conduct a thorough investigation and obtain relevant evidence in the absence of the complainant's cooperation.

Where the complainant remains committed to the requests above, and the alleged Prohibited Conduct does not fall under Title IX Sexual Misconduct (policy Section 13.0), but under Sexual Misconduct under the California Education Code (policy Section 14.0) and/or Sex- and Gender based Discrimination as defined in policy Section 15.0, the Title IX Coordinator may elect to pursue action on Caltech's behalf without considering the above factors.

Where Caltech determines that it can honor the student's request for confidentiality or for the complaint not to be pursued, it shall still take reasonable steps to respond to the complaint, consistent with the request, to limit the effects of the alleged Prohibited Conduct and

prevent its recurrence without initiating formal action against the alleged respondent or revealing the identity of the complainant. These steps may include increased monitoring, supervision, or security at locations or activities where the alleged misconduct occurred; providing additional training and education materials for students and employees; or conducting climate surveys regarding sexual violence. The Institute shall also take immediate steps to provide for the safety of the complainant while keeping the complainant's identity confidential as appropriate. These steps may include changing living arrangements or course schedules, assignments, or tests. The complainant shall be notified that the steps Caltech will take to respond to the complaint will be limited by the request for confidentiality.

If Caltech determines that it must disclose the complainant's identity to the respondent or proceed with an investigation, it shall inform the complainant prior to making this disclosure or initiating the investigation. The complainant is not required to participate in the ensuing process. Caltech shall also take immediate steps to provide for the safety of the complainant where appropriate. In the event the complainant requests that Caltech inform the respondent that the student asked Caltech not to investigate or seek discipline, Caltech shall honor this request.

X. Notification of Right to File a Criminal Complaint

If the complaint includes allegations that may constitute a possible crime, the Title IX Coordinator will notify the complainant of their right to file a criminal complaint or to choose not to notify law enforcement. Caltech does not report sex- and gender-based misconduct to law enforcement on a complainant's behalf, unless such a report is mandated by law (e.g., sexual assault of a person under 18, de-identified reporting as required under California Education Code Section 67383). If the complainant chooses to notify law enforcement, they may seek the assistance of the Equity and Title IX Office. The Equity and Title IX Office will facilitate the contact with law enforcement and the scheduling of a meeting, if the complainant chooses to make a report. In compliance with Title IX and FERPA, Caltech will not provide information regarding parties and witnesses to law enforcement, unless required by a subpoena, other court order, or as otherwise required by law or permitted consistent with this policy.

XI. Filing a Formal Complaint

In order to exercise resolution options for addressing and resolving complaints of alleged Prohibited Conduct covered under these Procedures, the complainant must file a formal complaint document with the Title IX Coordinator in person or by regular or electronic mail requesting that Caltech initiate a complaint resolution process. The document must contain the complainant's physical or digital signature or otherwise indicate that the complainant is the person filing the formal complaint.

At the time of filing a formal complaint, a complainant must be participating in or attempting to participate in an education program or

activity of Caltech. The term "attempting to participate" includes when a complainant has: (a) applied for admission; (b) graduated but intends to apply for a new program; (c) graduated but intends to participate in alumni programs and activities; (d) gone on leave but is still enrolled; (e) gone on leave but intends to re-apply after the leave; or (f) withdrawn due to alleged sexual harassment and expresses a desire to re-enroll if Caltech responds appropriately to the allegations.

The term "education program or activity" includes Prohibited Conduct occurring in locations, events, or circumstances, on or off-campus, over which Caltech exercised substantial control over both the respondent and the context in which the alleged Prohibited Conduct occurred, and also includes any building owned or controlled by a student organization that is officially recognized by Caltech. For reports of conduct occurring off-campus, the Title IX Coordinator will determine whether the alleged Prohibited Conduct occurred in a Caltech education program or activity.

However, even if a complainant is not qualified to bring a formal complaint, the respondent is outside the jurisdiction of Caltech's policy, or the alleged Prohibited Conduct took place outside of Caltech's educational programs and activities, if there is any reason to believe that the alleged Prohibited Conduct could contribute to a hostile educational environment, interfere with a student's access to education, or otherwise compromise the safety of the Caltech community, Caltech will still take prompt action, as warranted and appropriate, to provide for the safety and well-being of the individual reporting and the campus community, including taking reasonable steps to stop and remedy the effects of the Prohibited Conduct and to prevent recurrence of the behavior. This may include the Title IX Coordinator's initiating a formal complaint under these procedures on their own authority on Caltech's behalf or initiating an investigation process under the Unlawful Harassment and Abusive Conduct Policy. If other Institute policies are implicated, the Title IX Coordinator may also refer the matter to the appropriate office for follow-up.

Where the Title IX Coordinator initiates activity under these Procedures on their own authority on behalf of Caltech, the formal complaint requirements must still be met and the complainant would still be treated as a party with all associated rights parties have under the formal complaint resolution procedures.

XII. Dismissal of a Formal Complaint

Upon receiving a formal complaint, within fourteen (14) business days, the Title IX Coordinator will dismiss the complaint for resolution under these procedures if the conduct alleged does not constitute sexual harassment, as defined either under Title IX (policy Section 13) or the California Education Code (policy Section 14). If the conduct alleged does not fall under either section, the Title IX Coordinator, if appropriate, will refer the allegations for resolution under other appropriate Caltech policies and procedures, including the Unlawful Harassment Policy and related procedures.

The Title IX Coordinator may also dismiss a formal complaint or allegations therein if at any time during a resolution process a

complainant notifies the Title IX Coordinator in writing that they would like to withdraw their complaint or certain allegations; if the respondent is no longer enrolled or employed at Caltech; or if, as determined by the Title IX Coordinator, specific circumstances prevent Caltech from gathering evidence sufficient to reach a determination as to the complaint or certain allegations. The Title IX Coordinator will promptly and simultaneously send written notice to the parties of any dismissal and the reason(s) for the dismissal.

The parties may submit an appeal of any dismissal decision, in writing, to the Associate Vice President of Human Resources, within ten (10) business days of receiving the dismissal decision. The appeal of a dismissal of a formal complaint, or of certain allegations therein, is limited to one or more of the following grounds: a procedural irregularity that affected the dismissal decision; new evidence (including a new witness) that was not reasonably available at the time of the dismissal decision that could affect that decision; and the Title IX Coordinator, investigator(s), or decision maker(s) had a conflict of interest or bias for or against complainants or respondents generally or the individual complainant or respondent that affected the dismissal decision. If a party submits an appeal of a dismissal, the other party will have the opportunity to submit a written response to the appeal within ten (10) business days of the filing of the appeal. The parties simultaneously will be informed, in writing, of the outcome of the appeal. The appeal decision letter will state the rationale for the result. Appeal decisions are final.

Even where dismissal of a formal complaint occurs, the Title IX Coordinator may still provide supportive measures to parties or take other appropriate action in response to alleged concerns.

A formal complaint will not be dismissed, and a resolution process will not be discontinued, merely because it has not concluded before an undergraduate or graduate student has graduated. Caltech may continue the process, even if the graduated student elects not to participate in the process. Caltech will not delay graduation or deny a degree on the ground that this process is ongoing. Caltech may, however, document, and communicate to other institutions or employers, when authorized and appropriate, that a former student declined to participate in a pending Title IX process, including where such non-participation resulted in the dismissal of a complaint.

XIII. Consolidation of Formal Complaints

The Title IX Coordinator may consolidate formal complaints of allegations covered under these procedures against more than one respondent, or by more than one complainant against one or more respondents, or by one party against the other party, where the allegations arise out of the same facts or circumstances.

XIV. Notice of Allegations

Upon receiving or initiating a formal complaint, within ten (10) business days, the Title IX Coordinator must provide written notice to the parties of the following, with sufficient time for the parties—generally ten (10) business days—to prepare a response before any initial interview:

1. resolution processes set out below;
2. allegations, including sufficient details known at the time, including the identities of the parties involved in the incident, if known, the misconduct alleged, and the date and location of the alleged incident, if known;
3. alleged institute policy violations under review;
4. procedures that will be used;
5. statement that the respondent is presumed not responsible for the alleged misconduct and that a determination regarding responsibility is made at the conclusion of an investigation process or by an administrative resolution in which the respondent takes responsibility for the alleged misconduct;
6. that the parties may have an advisor of their choice, who may be, but is not required to be, an attorney, accompany them at any stage of the process;
7. that the parties may review and inspect evidence under an investigation process; and

that knowingly making false statements or submitting false information is prohibited and may subject the offending party to discipline;

1. information regarding appropriate counseling and other support resources developed and maintained by the Institute;
2. copies of the policy and pertinent procedures.

Any new allegations that arise during the course of the investigation that could subject either party to new or additional sanctions shall be subject to these same notice requirements.

XV. Resolution Options

The outcomes of each of the four options set out below—the remedy-based resolution, the administrative resolution, mediation, and the investigation, subject to any appeal process—are considered final. Once one option has concluded, a party may no longer exercise another option regarding the same alleged conduct. However, a party may elect to raise or pursue another option *before* the option currently being pursued has concluded.

Any person designated by Caltech to facilitate any of the resolution processes set out below (e.g., Title IX Coordinator, investigator, mediator, decision maker, administrator who determines sanctions and remedies, administrator hearing an appeal of an outcome of an investigation process) may not have a conflict of interest or bias for or against complainants or respondents generally or an individual complainant or respondent. Parties will be provided an opportunity at

appropriate junctures in a process to object to a person carrying out a facilitation role in the process for the consideration and decision of the Title IX Coordinator on the grounds of a conflict of interest or bias. Where an objection is made about the Title IX Coordinator, the decision as to their suitability will be made by the Associate Vice President for Human Resources. Determination of whether a conflict of interest or bias exists in a particular instance will be a matter of judgment involving all the material facts of the situation.

In addition, any person designated by Caltech to facilitate any of the resolution processes set out below (e.g., Title IX Coordinator, investigator, decision maker, mediator, administrator who determines sanctions and remedies, administrator hearing an appeal of an outcome of an investigation process) will receive training that is trauma-informed and comprehensive and that includes information appropriate to their respective roles.

The Administrative Resolution process, the Mediation process, and the Remedy-Based Resolution process are available only at the discretion of the Title IX Coordinator under circumstances they deem appropriate. Civil law remedies may also be available to complainants. A complainant may, on their own, choose to pursue any such remedies independent of and in addition to any of Caltech's resolution processes. Caltech does not provide legal advice about civil law remedies or criminal justice options.

A complainant may report to law enforcement and pursue available criminal justice options, in addition to filing a formal complaint and exercising one of the Caltech resolution processes set out below. In deciding the scope of their participation in resolution processes, parties should consider that statements and evidence provided in the course of a resolution process may be produced to law enforcement in compliance with a subpoena or other court order and used in a civil or criminal proceeding.

A. Administrative Resolution

The Title IX Coordinator, with the voluntary written consent of the parties, may offer the opportunity to resolve the complaint by Administrative Resolution (AR). The AR option provides an opportunity for the respondent to accept responsibility for their alleged conduct and proceed to a resolution without a formal investigation. Complainants and respondents participating in this process may have an advisor of their choice accompany them when engaging in this resolution process.

If the AR option is agreed to by a complainant, the Title IX Coordinator will meet with the respondent to review the allegations. The Title IX Coordinator will provide the respondent with information on the respondent's rights and options under the policy and these procedures. The Title IX Coordinator will also provide the respondent with written materials outlining information on campus support resources and services, including their contact information and days and hours of availability.

The Title IX Coordinator will offer the respondent the opportunity to resolve the complaint by AR by accepting responsibility for the alleged

conduct. It is the respondent's option and decision whether to do so. If the respondent elects to acknowledge that the alleged conduct occurred and takes responsibility for the alleged conduct, the respondent will sign a written acknowledgement, and the matter will be referred to the appropriate decision maker for a decision concerning sanctions and remedies that may be appropriate.

Generally, for purposes of determining sanctions in connection with an AR, the decision maker shall be determined based upon the respondent's affiliation (the vice provost of research or administration for faculty, the assistant vice president for human resources for postdoctoral scholars and campus staff, or the deputy director for Human Resources at JPL for JPL employees). In the case of student respondents, the appropriate dean will serve as the decision maker.

In determining sanctions and remedies, decision makers will consult with the Title IX Coordinator and may consult with any other individual they deem appropriate.

The parties will both be notified simultaneously in writing of the resolution, including any sanctions and remedies. Within ten (10) business days of receiving this letter, either party may appeal in writing.

An AR process will be concluded within a reasonably prompt time frame after the complaint has been made, generally forty-five (45) business days. The Title IX Coordinator will keep the parties informed of the status of the process. The Title IX Coordinator may delay the process temporarily or extend the time frame for good cause, providing written notice to the parties of any delays or extensions and the reasons therefor. Good cause may include but is not limited to the absence of a party or a party's advisor; the need for language assistance or accommodation of disabilities; the breadth and scope of the allegations and number of parties; and office closures.

If a resolution is not reached under this process within a reasonable amount of time, or if the Title IX Coordinator determines that one or both parties are not participating in good faith or a timely or appropriate manner in the process, the Title IX Coordinator may terminate the process, and the complainant may pursue other applicable resolution options.

An AR is the final resolution of the allegations contained therein.

B. Remedy-Based Resolution

The Remedy-Based Resolution (RBR) is not available to resolve allegations made by a student of Title IX-covered Prohibited Conduct set out in the Prohibited Conduct under Title IX section of the policy against a Caltech employee. The Title IX Coordinator determines whether an RBR is an otherwise appropriate option for resolving the allegations at issue, depending on their assessment of the allegations and circumstances.

The RBR option is a mutual non-disciplinary agreement entered into among Caltech and the parties to a formal complaint. In a RBR, a respondent agrees to undertake, or all parties agree to undertake, certain social, academic, and/or administrative steps, on a certain timeline, as a means of resolving a complaint of Prohibited Conduct

without an investigation and a finding regarding responsibility. All parties, and the Title IX Coordinator on behalf of Caltech, must voluntarily agree to, and sign a written agreement setting out, all the terms of the RBR as the complete and final resolution of the formal complaint(s). In other words, if an agreement is reached, the complainant cannot subsequently file a formal complaint for an investigation regarding the same alleged conduct, unless a respondent does not fulfill their agreed upon commitments under the RBR as determined by the Title IX Coordinator.

Complainants and respondents participating in this process may have an advisor of their choice accompany them when engaging in this resolution process. Key aspects of an RBR include that it:

- is a voluntary process when available to resolve allegations;
- focuses on non-disciplinary remedies to address the concerns underlying the alleged Prohibited Conduct. For example, under an RBR, a respondent can agree to undertake a counseling and/or education program to address behavioral issues.
- provides a measure of input to the complainant in crafting measures and remedies undertaken by the respondent, allowing the complainant to focus on remedying specific social, academic, or administrative concerns; and
- does not involve an adjudication of the allegations and a potential finding of responsibility against the respondent.

In cases in which the Title IX Coordinator determines an RBR may be appropriate, the Title IX Coordinator will discuss options with a complainant. If all parties to a formal complaint provide voluntary written consent to engage in the RBR process, the Title IX Coordinator will work with the parties separately to negotiate and craft the agreement. The parties do not engage directly with one another. The Title IX Coordinator, with the consent of the parties, may seek the assistance of academic and administrative leadership, as appropriate, to make possible and implement elements of the agreement.

An RBR process culminating in a signed agreement will be concluded within a reasonably prompt time frame after the complaint has been made, generally forty-five (45) business days. The Title IX Coordinator will keep the parties informed of the status of the process. The Title IX Coordinator may delay the process temporarily or extend the time frame for good cause, providing written notice to the parties of any delays or extensions and the reasons therefor. Good cause may include but is not limited to the absence of a party or a party's advisor; the need for language assistance or accommodation of disabilities; the number of parties; and office closures.

If a resolution is not reached under this process within a reasonable amount of time, or if the Title IX Coordinator determines that one or both parties are not participating in good faith or a timely or appropriate manner in the process, the Title IX Coordinator may terminate the process, and the complainant may pursue other applicable resolution options.

A Remedy-Based Resolution is the final resolution of the allegations it addresses, unless a party fails to carry out their commitments under the agreement, as determined by the Title IX Coordinator.

C. Mediation

The Mediation Process is not available to resolve allegations made by a student of Title IX-covered Prohibited Conduct set out in the Prohibited Conduct under Title IX section of the policy against a Caltech employee. In appropriate cases, as determined by the Title IX Coordinator, Mediation may be offered as a resolution option to resolve a formal complaint. The Title IX Coordinator will discuss with each party potential elements of a mediation agreement pertinent to their concerns and allegations to help them determine whether Mediation is an option they wish to pursue.

Mediation is a voluntary process where a facilitator (mediator) works with the complainant and respondent and Caltech (represented by the Title IX Coordinator) to attempt to reach a mutually agreeable resolution of a formal complaint of Prohibited Conduct (Mediated Resolution). A Mediated Resolution will be reflected in a written agreement signed by the parties and the Title IX Coordinator, on behalf of Caltech. A Mediated Resolution entered into by the parties and Caltech is the final resolution of the complaint and the allegations therein (i.e., the complainant cannot subsequently file a formal complaint for an investigation regarding the same alleged conduct), unless a party fails to carry out their commitments under the Mediated Resolution Agreement, as determined by the Title IX Coordinator.

A Mediation is different than a Remedy-Based Resolution in that the elements of the agreement may include disciplinary sanctions. As with an RBR, there are no formal findings of responsibility in a Mediation process. However, in a Mediation process, measures that otherwise may be imposed as a sanction as a result of a finding of responsibility may be agreed upon by the parties, including Caltech, in the context of
a mediated resolution.

If all parties to a formal complaint provide voluntary written consent to engage in the Mediation process, the Title IX Coordinator will assign a mediator who will work with the parties to negotiate and prepare the agreement. The Title IX Coordinator has the discretion to elect to conduct the mediation or may appoint another appropriately trained individual to conduct the mediation. The Title IX Coordinator will notify the parties of their right to and process for objecting to the mediator on the basis of conflict of interest or bias.

During a Mediation, the parties do not engage directly with one another. The Title IX Coordinator, with the consent of the parties, may seek the assistance of academic and administrative leadership, as appropriate, to make possible and implement elements of the Mediated Resolution agreement.

A Mediation process culminating in a signed agreement will be concluded within a reasonably prompt time frame after the complaint has been made, generally sixty (60) business days. The Title IX Coordinator will keep the parties informed of the status of the process.

The Title IX Coordinator may delay the process temporarily or extend the time frame for good cause, providing written notice to the parties of any delays or extensions and the reasons therefor.

If a resolution is not reached under this process within a reasonable amount of time, or if the Title IX Coordinator determines that one or more parties are not participating in good faith or a timely or appropriate manner in the process, the Title IX Coordinator may terminate the process, and the complainant may pursue other applicable resolution options.

Complainants and respondents participating in this process may have an advisor of their choice accompany them when engaging in this resolution process.

D. Facilitation of Administrative Resolution, Mediation, or Remedy-Based Resolution During Investigation and Adjudication Process

At any time following the filing of a formal complaint, including during an investigation process, prior to reaching a final determination regarding responsibility, inclusive of any appeal process, the Title IX Coordinator may facilitate an administrative resolution (AR), Mediation, or a Remedy-Based Resolution (RBR), if determined to be appropriate, provided that the Title IX Coordinator:

1. Provides to the parties written notice disclosing the allegations, the requirements, and consequences of the AR, Mediation, or RBR process, including that: (a) completing such a resolution process precludes the parties from initiating or resuming a formal complaint arising from the same allegations; (b) at any time prior to completing the AR, Mediation, or RBR process, either party has the right to withdraw and initiate or resume the investigation process; and (c) notice of records that will be maintained or could be shared and with whom.
2. Obtains the parties' voluntary written consent to the AR, Mediation, or RBR process.

E. The Investigation and Adjudication Process

The Investigation and Adjudication Process provides both parties with an investigation and adjudication of the allegations. The purpose of the investigation is to gather the evidence relating to the complaint, and decisions are based on an objective evaluation of all relevant evidence, including both inculpatory and exculpatory evidence. Evidence may include statements from the parties and witnesses; documents relating to the complaint, such as texts, photographs, and emails; and physical evidence, such as clothing, rape kit evidence, and weapons.

All participants in an investigation will receive a fair and impartial process and be treated with dignity, care, and respect. Caltech's policy and investigation procedures are intended to ensure that individuals reported for Prohibited Conduct are not prejudged and are provided with adequate notice and an opportunity to be heard regarding the allegations made against them. Respondents are

presumed not responsible for the alleged conduct until a determination regarding responsibility is made at the conclusion of the investigation process. The investigation will be trauma-informed and impartial. Those involved in questioning parties and witnesses—namely, the Title IX Coordinator and Title IX deputies, the investigator(s) and the decision maker—will receive training in conducting fair and trauma-informed investigations and hearings.

The Investigation and Adjudication Process is not an adversarial process between the complainant, the respondent and the witnesses, but rather a process by which Caltech complies with its obligations under existing law. The complainant does not have the burden to prove, nor does the respondent have the burden to disprove, the allegations of Prohibited Conduct.

If the decision maker determines that a preponderance of the evidence substantiates alleged Prohibited Conduct, in violation of the Sex Discrimination Policy, sanctions, remedies, or systemic remedies, as appropriate, will be imposed. The decisions made by the decision maker, subject to the resolution of any appeal, represent the final resolution of the formal complaint, whether or not a respondent is found responsible.

Privacy and Confidentiality During the Investigation and Adjudication Process

The Investigation and Adjudication Process will be treated as private to the extent possible. Caltech administrators will be informed on a need-to-know basis. Caltech will make reasonable and appropriate efforts to preserve the privacy of the parties and witnesses and protect the confidentiality of information. With the exception of the hearing portion of the investigation process, as set out below, no meetings or conversations that take place as part of the investigation process may be recorded by anyone. Investigation files, including the recording of the hearing, will be maintained by the Equity and Title IX Office.

The following documents, which will be shared with the parties, are considered Confidential Materials by Caltech and any inappropriate copying, printing, emailing, photographing, downloading, or posting on social media of such materials may subject the disclosing party to disciplinary action for violation of Caltech policy protecting confidentiality or other Caltech policies, including Caltech's Honor Code, and, further could subject the disclosing party, to an allegation by a party of retaliation or harassment: the draft and final evidence reports, including the appendices of evidence, and the hearing transcript.

It is permissible for a party to share the Confidential Materials with attorneys for the purpose of seeking legal advice or with any non-attorney advisor they have in the process, and it is permissible to share the contents of the materials with others to obtain informational or emotional support from family, therapists, or others to exercise any rights under the investigation process, including writing a response to the draft investigation report or preparing for the hearing.

Nothing in these Procedures shall be understood to restrict the ability of the Parties to discuss the allegations under investigation for

the purpose of gathering and presenting relevant evidence.

Investigative Timeline
Complaints will be investigated and resolved within a reasonably prompt time frame after the complaint has been made, generally 120 business days.

The Title IX Coordinator will provide the parties written updates of the status of the investigation at least every thirty (30) business days, including the date by which the parties shall be notified of the outcome of the investigation and the deadlines and process for parties to appeal. The Title IX Coordinator may delay the investigation process temporarily or extend the time frame for good cause, as provided in Section III, providing prompt written notice to the parties of any delays or extensions and the reasons therefor.

Concurrent Legal Proceedings
Caltech's investigation and adjudication process will occur independently from any legal/criminal proceedings that may take place. When a Complaint is made under the Policy, as well as to law enforcement, Caltech may, at the Title IX Coordinator's discretion, delay its process for a reasonable amount of time if a law enforcement agency requests this delay to allow law enforcement to gather evidence of criminal misconduct. Such delay would constitute good cause for extending the timeline.

Limitations on Questions
The investigator(s) and decision maker will not ask parties or witnesses questions that are repetitive, irrelevant, or harassing. Consistent with federal and state law, the investigator(s) and the decision maker will not ask questions or seek evidence of a complainant's or respondent's prior or subsequent sexual conduct with anyone other than the respondent, except to the extent such questions and/or evidence are used to determine whether someone other than the respondent committed the conduct alleged by the complainant. Furthermore, evidence of a prior consensual sexual, romantic, or intimate relationship between the complainant and respondent does not by itself imply consent or preclude a finding of Prohibited Conduct. The investigator(s) and decision maker shall not consider the existence of a dating relationship or prior or subsequent consensual sexual relations between the parties unless the evidence is relevant to how the parties communicated consent in prior or subsequent consensual sexual relations. Where the investigator(s) or decision maker allow consideration of evidence about a dating relationship or prior or subsequent consensual sexual relations between the parties, the mere fact that the parties engaged in other consensual sexual relations with one another is never sufficient, by itself, to establish that the conduct in question was consensual.

Before allowing the consideration of any evidence described in this section, the investigator(s) or decision maker shall provide a written explanation to the parties as to why consideration of the evidence meets the requirements for consideration.

The investigation, at any stage, will not require, allow, rely upon, or use questions or evidence that constitute or seek the disclosure of information protected under a legally recognized privilege (e.g., attorney-client, doctor-patient, clergy-penitent), unless the person holding such privilege has waived the privilege. Questions that seek information about any party's medical, psychological, and similar records are not permitted unless the party has given written consent.

Procedural Steps for Investigation

1. Initiation of the Invesitigation Process

a) Notification to Parties: The Title IX Coordinator initiates the investigation process with a notification sent to both parties. The Title IX Coordinator will assign appropriate investigator(s) to carry out the investigation. The initial notification will identify the assigned investigator(s) and will notify the parties of their right to and process for objecting to either of the investigator(s) or to the Title IX Coordinator on the basis of conflict of interest or bias. The notification will include the estimated date by which the parties will be notified of the outcome of any investigation.

b) Advisor of Choice. The complainant and respondent may have an advisor of their choice, in accordance and subject to the requirements of these procedures and the Advisor Policy.

c) Conflict of Interest. The Title IX Coordinator or associate vice president of human resources, as appropriate, will consider any objections by the parties on the basis of conflict of interest or bias and determine the Title IX Coordinator and investigator(s) for the process.

2. Investigation and Investigative Report

a) Party Interviews. After a reasonable amount of time to review the notice of allegations and applicable policies and procedures, the parties will be given equal opportunity to meet with the investigator(s). In those meetings, the investigator(s) will seek and gather evidence about the allegations, including any documents or physical evidence, as well as the identification and location of witnesses. The parties may submit written statements and evidence to the investigator(s) that document their experiences.

Each party is free to choose to meet or not to meet with the investigator(s), or otherwise free to choose to participate or not to participate in the investigation process. Regardless of the scope of a party's participation, the party would still be treated as a party with all associated rights—for example, the right to review and inspect draft and final evidence reports and appendices of evidence, to provide a written response to the draft evidence report to the investigator(s) for consideration and potential follow up, to submit questions for the decision maker before and during the hearing, to attend the hearing and observe the testimony of other parties and witnesses, to receive a copy of the decision regarding responsibility, and to submit an appeal of that decision in keeping with the appeal process.

In deciding the scope of their participation, parties should consider that statements and evidence provided in the course of an

investigation may be produced to law enforcement in compliance with a subpoena or other court order and used against them in a civil or criminal proceeding.

b) Proffer of Evidence by Parties. Throughout the process, the parties may suggest witnesses and documents to the investigator(s) as well as questions for the investigator(s) to ask the other party and any witnesses. The investigator(s) will determine whether the suggestions are relevant and appropriate.

The parties may not, however, engage in coercion, pressure, undue influence, or retaliation with respect to potential witnesses or other parties in the course of identifying evidence for the investigator(s). The parties may seek guidance from the Title IX Coordinator and the investigator(s) on avoiding these concerns. Communications between parties and witnesses deemed to have resulted from coercion, pressure, undue influence, or retaliation may be discounted altogether by the decision maker or may be considered by the decision maker in making credibility determinations and weighing evidence deemed subject to the undue influence.

c) Collection of Evidence. The investigator(s) will interview relevant witnesses and gather other evidence related to the allegations, if any. Witnesses may submit documents or written statements to the investigator(s).

Parties and witnesses who elect to participate in the Investigation and Adjudication Process are expected to do so in good faith and in a timely, reasonable, and appropriate manner. If the Title IX Coordinator determines that an individual is not complying with this expectation (e.g., failing to schedule meetings with the investigator, not showing up to meetings, neglecting to provide evidence they said they would provide, failing to respond to the draft investigation report), the Title IX Coordinator may conclude the investigation phase without further opportunity by such individual to provide evidence.

d) Draft Investigative Reports. The investigator(s) will prepare a draft investigation report identifying the facts disputed by the parties for each allegation, as well as summarizing and identifying the relevant, related evidence gathered, including facts relevant to the credibility of parties or witnesses or items of evidence. The investigator(s) will also provide appendices containing the evidence gathered. The complainant and respondent will be given equal opportunity to review and respond to the investigation report. The report will also be provided to the parties' advisors. The parties will have at least ten (10) business days to submit a written response to the report. The investigator(s) will determine whether the parties' responses require any follow-up investigatory action or an opportunity for the other party to respond.

e) Final Investigative Reports. The investigator(s) will finalize the investigation report. This finalized investigation report will be provided to the parties and their advisors, and the decision maker at least ten (10) business days before any hearing.

3. Investigative Hearing

Where the investigation addresses allegations that ***only*** fall under the California Education Code (as defined in policy Section 14.0), the Title IX Coordinator will determine whether a hearing is necessary to determine whether that alleged Prohibited Conduct more likely than not occurred. In making this decision, Caltech will consider whether the parties elected to participate in the investigation, as well as the fact that each party had the opportunity to suggest questions for other parties, or witnesses, or both, during the investigation. If Caltech determines a hearing is necessary, that hearing will not involve any cross-examination of any party or witness conducted directly by a party or a party's advisor.

a) Identity of the Decision Maker. The Title IX Coordinator shall have the discretion to determine which appropriately trained individual will serve as the decision maker in the investigation process. The decision maker conducts any hearing that takes place under these procedures. Prior to any hearing, the parties will be notified of the identity of the decision maker and will be given an opportunity to object to that individual on the basis of a conflict of interest or bias.

b) Standard of Evidence. The decision maker will use the preponderance of evidence standard to determine whether the alleged Prohibited Conduct occurred. A preponderance of evidence means that it is more likely than not that the alleged Prohibited Conduct occurred. Stated another way, it means that the likelihood the alleged Prohibited Conduct occurred is any amount over 50%. The decision maker will make decisions on the disputed facts and decide whether the evidence makes it more likely than not that the alleged Prohibited Conduct occurred based on the evidence available at the time of the decision. When the decision maker is presented with two different but plausible versions of alleged Prohibited Conduct, credibility determinations may affect the outcome.

c) Hearing Logistics. At any hearing conducted under the investigation process, the decision maker will determine an appropriate and reasonable scope and time frame for the hearing, as well as logistical processes for the hearing, such as for making objections and submitting questions. The decision maker will meet face-to-face, in person or via video, with the parties, and others whom the decision maker deems appropriate, prior to deciding how to resolve the disputed facts.

Any hearing is private and closed to the public. Only the decision maker, the parties and their advisors, witnesses, appropriate administrators, and others determined by Caltech to be necessary to the hearing may attend.

The hearing will be conducted with the appropriate technology to allow the parties to virtually observe each other's meeting, and any witness meetings, with the decision maker while maintaining their physical separation. Parties or witnesses may request to appear by video from a remote location. Caltech will grant the request of any party that the entire hearing, including cross-examination, be held virtually. In making this request, the party does not need to provide a reason. In the absence of such a request, the Title IX Coordinator has

the discretion to allow any party or witness to appear at the hearing virtually, with technology enabling participants simultaneously to see and hear each other. Any requests for disability accommodations should be made to the Title IX Coordinator and Caltech's Accessibility Services Specialist.

All of the evidence that was made available previously in the investigation report will be made available at the hearing to give each party equal opportunity to refer to such evidence during the hearing. Generally, the parties are not permitted to introduce evidence, including witness testimony, at the hearing that the party did not identify during the investigation and that was available at the time of the investigation. However, the decision maker has the discretion to accept for good cause, or to exclude, such new evidence offered at the hearing.

The decision maker will comply, and ensure others when allowed to ask questions comply, throughout the hearing with the limitations on questioning section of these procedures.

d) Questioning by Decision Maker. The decision maker will question the parties and witnesses, if any, before making credibility determinations, and determine whether the allegations and any policy violations are substantiated by a preponderance of the evidence.

Before and during the hearing, the parties may submit written questions for the investigator(s) and decision maker to ask the other party and any witnesses with whom the decision maker is meeting (indirect cross-examination). The parties can submit written questions during the hearing through the appropriate technology while maintaining their physical separation. The decision maker will facilitate the questioning and may consult with the investigator(s). The decision maker will have the discretion to exclude any question(s) that they determine inappropriate. At the hearing, the other party shall have the opportunity to note an objection in writing to a question posed. Neither the decision maker nor Caltech is obligated to respond to the objection but may consider it and must include it in the record. The decision maker shall have the authority and obligation to discard or rephrase any question that the decision maker deems to be repetitive, irrelevant or harassing. In making these determinations, the decision maker is not bound by, but may take guidance from, the formal rules of evidence.

e) Cross Examination By Party Advisors. In addition, consistent with guidance issued by the Department of Education Office of Civil Rights, the following procedural steps in this paragraph apply ***only*** at hearings adjudicating allegations of Prohibited Conducted covered under Title IX (as defined in policy Section 13.0) and occurring, in whole or in part, on or after August 14, 2020: (i) each party's advisor (but not the parties themselves) may directly and orally ask the other party and any witnesses all relevant questions and follow-up questions, including those challenging credibility (direct cross-examination); (ii) before a party or witness answers an advisor's direct question, the decision maker must first determine whether the question is relevant and explain any decision to exclude a question as not relevant or otherwise inappropriate; and (iii) for the purpose of the

hearing only, if a party does not have an advisor, Caltech will provide without fee or charge to that party an advisor of Caltech's choice who may be, but is not required to be, an attorney, to conduct direct cross-examination on behalf of that party.

In conducting direct cross-examination of a party or witness, the advisor of a party may ask only those questions drafted by the party whom they are advising. The advisor may not ask questions their party has not drafted. The advisor, moreover, must maintain a calm and respectful tone throughout the direct cross-examination. An advisor may not make objections, statements, or arguments during the cross-examination or otherwise during the hearing. The decision maker may disqualify an advisor who does not follow these rules.

f) Party and Witness Participation at the Hearing. Caltech cannot compel either party, or any witness, to meet with the decision maker at the hearing or, when applicable, to answer direct cross examination questions. Parties or witnesses may choose to attend the hearing and not answer questions. The decision maker cannot draw an inference about responsibility or credibility based solely on a party's or witness's absence from the hearing or refusal to answer questions from the decision maker or, when applicable, a party's advisor during direct cross-examination. However, the Hearing Decisionmaker may choose to place less or no weight upon statements by a Party or witness who refuses to respond, or selectively responds, to relevant and permissible questions. The decision maker may re-evaluate the relevance of any question a party or witness refuses to answer after the hearing has concluded.

In deciding the scope of their participation in the hearing, individuals should consider that statements and evidence provided in the course of an investigation may be produced to law enforcement in compliance with a subpoena or other court order and used in a civil or criminal proceeding. Regardless of the scope of a party's participation in the hearing, the party would still be treated as a party with all associated rights.

g) Hearing Recording. Caltech will create an audio or audio-visual recording, or transcript, only of the hearing and make it available to the parties upon request for their inspection and review. No party, advisor, or witness is permitted to make independent recordings of the hearing or any other meeting or conversation that takes place under the investigation process.

h) Hearing Decision Report. The decision maker will resolve the disputed facts, make credibility determinations, and decide whether the allegations and any policy violations are substantiated by a preponderance of the evidence. In making these decisions, the decision maker will consider the final investigation report and appendices of evidence, the parties' responses to the draft investigation report, the information gathered in the hearing, and the decision maker's credibility assessments of those interviewed at the hearing, as appropriate. Credibility determinations may not be based on a person's status as a complainant, respondent, or witness. The potential conclusions the decision maker can reach include but are not limited to: a violation of Caltech's Sex Discrimination Policy occurred;

inappropriate behavior but no violation occurred; the complaint was not supported by the evidence; the complaint was brought without a reasonable good-faith basis.

After making these decisions, the decision maker will meet with the appropriate administrator who will determine any sanctions, remedies, and systemic remedies, in order to brief them on the process and factual findings and conclusions. That administrator will be identified and will determine any sanctions, remedies, and systemic remedies, if appropriate, in accordance with procedures.

The decision maker will notify the parties simultaneously of all of these determinations in writing. The letter will include:

1. a.
   i. identification of the allegations;
   ii. a description of the procedural steps taken from the receipt of the formal complaint through the determination of responsibility, including any notifications to the parties, interviews with parties and witnesses, site visits, methods used to gather other evidence, and hearings held;
   iii. findings of fact supporting the determination;
   iv. conclusions regarding the application of the Sex Discrimination Policy and any other applicable Caltech policy to the facts;
   v. a statement, and rationale for, the result as to each allegation, including a determination regarding responsibility and any sanctions, remedies, and systemic remedies determined by the appropriate administrator; and
   vi. procedures and permissible bases for the complainant and respondent to appeal.

4. Post-Hearing

a) The determinations regarding responsibility and sanctions, remedies, and systemic remedies become final either on the date that the parties are provided the result of any appeal, or if an appeal is not filed, the date on which an appeal would no longer be considered timely.

b) The Title IX Coordinator will be informed of the outcome of the investigation and any appeal in order to carry out their responsibilities to consult on and coordinate implementation of any sanctions, remedies, and systemic remedies, monitor outcomes, identify and address areas of needed education and training presented by the case, and assess and address effects on the campus climate.

5. Exceptions or Modifications to these Procedures

Exceptions or modifications to these procedures can be made at any time by the Title IX Coordinator, provost, deans or associate deans, associate vice president for human resources, or director for human resources at JPL in order to ensure these procedures promote fairness to both parties and compliance with the law.

XVI. Potential Sanctions, Remedies, and Systemic Remedies

If a violation of Caltech's Sex Discrimination Policy has occurred, appropriate sanctions, remedies, and systemic remedies, as appropriate, will be imposed. Generally, the appropriate administrator shall be determined based upon the respondent's affiliation (the vice provost for research or administration for faculty, the assistant vice president for human resources for postdoctoral scholars and campus staff, the deputy director for human resources at JPL for JPL employees, and the appropriate dean for student respondents). In determining sanctions, remedies, and systemic remedies, these administrators will consult with the Title IX Coordinator and may consult with any other individual they deem appropriate.

The appropriate administrator may impose any one or more of the following:

Sanctions

- Verbal warning;
- Training;
- Mandatory coaching;
- Mandatory substance abuse treatment;
- A formal written warning placed in the respondent's file;
- Exclusion from participation in certain activities for a specified period of time;
- Temporary or permanent exclusion from campus;
- Suspension of the right to accept new graduate students or postdoctoral scholars;
- Transfer of advisees;
- Removal from positions of administrative responsibility;
- Suspension from positions requiring supervision or interaction with students or other members of the Caltech community;
- Restricted access to Caltech premises;
- Restricted access to Caltech's educational programs or activities;
- Removal from Caltech housing;
- Removal from a supervisory position;
- Involuntary leave of absence/suspension;
- Expulsion;
- Termination of employment;
- Permanent separation from the Institute;
- Revocation of admission;
- Delay or revocation of degree.

Remedies

- Access to counseling services and assistance in setting up initial appointment, both on and off campus;
- Imposition of "No-Contact Letter;" where a no-contact directive is issued after a finding of responsibility has been made, it shall be unilateral and apply only against the party found responsible;
- Rescheduling of exams and assignments, and reassignment of grading or other evaluative responsibilities (in conjunction with appropriate faculty and deans as necessary);

- Providing alternative course completion options (with the agreement of the appropriate faculty);
- Change in class schedule, including the ability to take an "incomplete," drop a course without penalty, or transfer sections (with the agreement of the appropriate faculty);
- Change in work schedule or job assignment;
- Change in on-campus housing, when feasible;
- Arranging to dissolve a housing contract and prorating a refund in accordance with campus housing policies;
- Assistance from Caltech support staff in completing housing relocation;
- Limiting an individual or organization's access to certain Caltech facilities or activities pending resolution of the matter;
- Voluntary leave of absence;
- Providing an escort to ensure safe movement between classes and activities;
- Providing medical services;
- Providing academic support services, such as tutoring;
- Any other remedy that can be tailored to the involved individuals to reasonably achieve the goals of this policy.

Systemic Remedies

- Institute-wide, division-wide, and/or option-wide, or other team-based communication or outreach effort and training, as appropriate;
- Addition of information to Equity and Title IX Office website, or other Institute website, as appropriate;
- Conduct of appropriate climate survey to gather information pertinent to preventative outreach efforts.

If the respondent was found not to have violated Caltech's Sex Discrimination Policy, but the investigation concluded that they committed some other wrongful or improper act, appropriate corrective action will be taken. Effective corrective action may also require remedies for a complainant and/or systemic remedies for the broader Caltech community. Caltech will take appropriate measures to prevent the reoccurrence of any Prohibited Conduct, and to correct and prevent any discriminatory or retaliatory effects, as appropriate.

In determining sanctions, remedies, and/or systemic remedies, the administrator will consult with the Title IX Coordinator and other persons they deem appropriate, to enable Caltech to take steps to prevent recurrence of any harassment and to correct its discriminatory effects on the complainant and, if appropriate, others.

The Institute may undertake remedies and systemic remedies, as appropriate, to safeguard a complainant's access to education, at any time. The complainant's engagement in a resolution process is not a prerequisite for such Institute action.

XVII. Disclosure of Outcomes

Outcomes of disciplinary proceedings may be disclosed consistent with applicable law, including FERPA, Title IX, and the Clery Act.

Outcomes of the Investigation and Adjudication Process will be disclosed on a need-to-know basis, as determined by the Title IX Coordinator, in order to effect sanctions and/or other remedies and systemic re

XVIII. Appeal

Appeals may be submitted by either party. They must be in writing and submitted within ten (10) business days of notification of the decision to the appropriate administrator (the provost for faculty, the associate vice president for human resources for postdoctoral scholars and campus staff, the vice president of student affairs for students, or, the director for human resources at JPL for JPL employee respondents). In assessing appeals, these administrators may consult with any individual they deem appropriate. The recipient of the appeal will notify the Title IX Coordinator and any other party in writing when an appeal is filed.

Appeals of decisions resulting from the investigation process are limited to one or more of the following grounds: (a) a procedural irregularity that affected the outcome of the matter; (b) new evidence (including a new witness) that was not reasonably available at the time the determination regarding responsibility was made and that could affect the outcome of the matter; (c) the Title IX Coordinator, investigator(s), decision maker(s), or administrator who determined and imposed any sanctions or remedies had a conflict of interest or bias for or against complainants or respondents generally or the individual complainant or respondent that
affected the outcome of the matter; or (d) the sanctions or remedies are substantially disproportionate to the conduct for which the respondent was found responsible.

If a party submits an appeal, the other party will have the opportunity to submit a written response to the appeal within ten (10) business days of the filing of the appeal. The parties simultaneously will be informed, in writing, of the outcome of the appeal. The appeal decision letter will state the rationale for the result. Appeal decisions are final.

If the appeal is granted in whole or in part, the administrator deciding the appeal will inform the Title IX Coordinator, the decision maker, and/or other appropriate Caltech administrator(s) so that appropriate follow up action can be taken to implement the appeal decision.

If the appeal is granted based on ground that the sanctions or remedies are substantially disproportionate to the conduct, the appeal administrator will determine what sanctions or remedies are appropriate, if any, and their decision is final.

XIX. Further Complaints

If the corrective action does not end the Prohibited Conduct, the complainant should immediately notify at campus the Title IX Coordinator, or a deputy Title IX Coordinator, the provost or a division chair, dean or associate dean, Employee and Organizational Development director; or at JPL, the Deputy Title IX Coordinator. In such cases, the complainant has the right to file another formal complaint based on new Prohibited Conduct.

XX. Title IX Coordinators

The Title IX Coordinator is responsible for coordinating Caltech's compliance with Title IX and for Caltech's overall response to Prohibited Conduct falling under Title IX. The Title IX Coordinator oversees the implementation and application of this policy and the related procedures to ensure the prompt and equitable resolution of complaints and the consistent treatment of the parties involved. In doing so, the Title IX Coordinator oversees all Title IX-covered and other sex- and gender-based misconduct complaints, monitors outcomes, identifies and addresses any patterns of systemic problems that arise, and assesses effects on the campus climate.

The Title IX Coordinator is supported by deputy Title IX Coordinators, all of whom can answer questions regarding Caltech's Title IX-related policies and Title IX.

Title IX Coordinator and
Assistant Vice President for Equity and Equity Investigations:
Lynzie De Veres
(626) 395-3132, equity@caltech.edu, 205 Center for Student Services

Assistant Deputy Title IX Coordinator and Civil Rights Resolution Specialist:
MacKenzie Stewart
(626) 395-1743, mstewart@caltech.edu, 215 Center for Student Services

Assistant Deputy Title IX Coordinator and Civil Rights Resolution Specialist:
Lauren Lockwood
(626) 395-4424, lauren@caltech.edu, 215 Center for Student Services

Deputy Title IX Coordinator for Staff and Postdoctoral Scholars and
Director, Employee and Organizational Development:
Ofelia Velazquez-Perez
(626) 395-3819, Ofelia.Velazquez-Perez@caltech.edu, 206 Central Engineering Services

Deputy Title IX Coordinator for JPL:
Jackie Clennan-Price
(818) 393-0016, Jackie.A.Clennanprice@jpl.nasa.gov, Human Resources T1720-165 at JPL

The following persons are authorized to initiate corrective action in response to reports of Prohibited Conduct covered under Prohibited Conduct under Title IX and the California Education Code on Caltech's behalf: Title IX Coordinator, Deputy Title IX Coordinators, Director of

Employee and Organizational Development, Associate Vice President for Human Resources, and JPL Director for Human Resources.

Related Policies and Procedures

- Sex- and Gender-Based Misconduct Policy
- Nondiscrimination and Equal Employment Opportunity Policy
- Unlawful Harassment and Abusive Contact Policy
- Procedures for Complaints of Unlawful Discrimination, Harassment and Retaliation
- Violence Prevention Policy

SUBSTANCE ABUSE

1.0 Policy

Caltech is committed to providing a safe, healthy, and productive work and academic environment for all members of the Caltech community. Consistent with the Drug-Free Workplace Act of 1988 and the Drug-Free Schools and Communities Act Amendments of 1989, it is Caltech's policy to maintain a work and academic environment free from drug and alcohol abuse. Faculty, staff, postdoctoral scholars, students, visitors, volunteers, and contractors performing work on Caltech's premises, including at the Jet Propulsion Laboratory ("JPL"), are required to comply with this policy.

2.0 Scope

2.1 Prohibited Conduct

The unlawful use, manufacture, distribution, cultivation, dispensation, possession, sale, purchase of, or offer to sell or purchase controlled substances or alcohol on the Caltech campus or its off-site locations, including JPL, or as any part of its activities, is prohibited. Controlled substances include, but are not limited to, amphetamines, cocaine, marijuana, opiates, phencyclidine (PCP) and their metabolites. **Irrespective of California law, marijuana still is a controlled substance under federal law, and therefore the use, manufacture, distribution, cultivation, dispensation, possession, sale, purchase of or offer to sell or purchase marijuana on the Caltech campus or its off-site locations, including JPL, or as any part of its activities, continues to be prohibited.** The recreational use of nitrous oxide is also prohibited under this policy.

In addition, every employee is prohibited from being under the influence of controlled substances, alcohol, or any substance that may impair the employee's ability to perform their job duties safely or productively, or that may otherwise impair their senses, coordination, or judgment while on duty, or at any time while on Caltech premises, at a Caltech sponsored event, or otherwise representing Caltech. Any employee reporting to work (or otherwise at work) under the influence of, or having present in their body, any prescribed drug, or medication that may adversely affect the employee's ability to work in a safe, productive, or efficient manner, must advise the Disability and Leave Unit. Caltech may require an employee to submit to drug and alcohol

testing consistent with Caltech policy and applicable federal and state law. Refusal by an employee to submit to a test will be treated as positive test result. Testing procedures that apply to JPL employees are available on the JPL Human Resources website.

2.2 Requirements for Employees and Students

As a condition of continued enrollment, every student is required to comply with this policy. As a condition of employment, all Caltech employees (this includes faculty, staff, postdoctoral scholars, and student employees), regardless of their location, are required to comply with this policy. A Caltech employee who violates this policy will be subject to disciplinary action up to and including termination of employment. A violation of this policy is likely to result in termination, even for a first offense. Similarly, all students, not just student employees, should understand that disciplinary action including involuntary leave or expulsion from Caltech may be invoked for violation of this policy and that intoxication is never an excuse for misconduct.

Caltech may contact a student's parents when a student under 21 violates this policy. If a student's behavior with respect to alcohol and drugs presents a danger to themselves or others, Caltech may inform the parents.

In addition, pursuant to federal law, a student's eligibility for federal financial aid may be suspended if the student is convicted, under federal or state law, of any offense involving the possession or sale of illegal drugs.

A faculty, staff, postdoctoral scholar, or student who is convicted (including a plea of nolo contendere [no contest]) of a criminal drug statute violation occurring in the workplace or on Caltech property must notify Caltech in writing within five (5) calendar days after the conviction. Campus employees should inform the assistant vice president of human resources, and students should inform their dean. JPL employees should inform the manager of employee relations.

2.3 Third Party Requirements

Persons who are not employees of Caltech but who perform work at Caltech for its benefit (such as contractors and their employees, temporary employees provided by agencies, volunteers, guests, and visitors engaged in joint projects at Caltech, etc.), are required to comply with this policy.

Violation of this policy is likely to result in being barred from the workplace even for a first offense.

3.0 Health Risks

The use of any mind- or mood-altering substance, including alcohol, can lead to psychological dependence, which is defined as a need or craving for the substance and feelings of restlessness, tension, or anxiety when the substance is not used. In addition, with many substances, use can lead to physical tolerance, characterized by the need for increasing amounts of the substance to achieve the same effect, and/or physical dependence, characterized by the onset of

unpleasant or painful physiological symptoms when the substance is no longer being used. As tolerance and psychological or physical dependence develop, judgment becomes impaired, and the individual often does not realize they are losing control over the use of the substance and that they need help.

It is impossible to predict accurately how an individual will react to a specific drug or to alcohol because effects vary depending on the person, environmental variables, the dosage and potency of the substance, the method of taking the substance, the frequency of use, and whether the substance is taken in conjunction with other substances. Illegal drugs have particularly unpredictable effects due to variability in dosage and purity. Further, the overall potency of street drugs has increased dramatically over the past two decades, making users increasingly susceptible to negative effects.

Alcohol acts as a depressant to the central nervous system and can cause serious short- and long-term damage. Short-term effects include nausea, vomiting, and ulcers; more chronic abuse can lead to brain, liver, kidney, and heart damage, and even to eventual death. Ingesting a large amount of alcohol at one time can lead to alcohol poisoning, coma, and death. Drugs such as LSD, amphetamines, marijuana, and alcohol alter emotion, cognition, perception, physiology, and behavior in a variety of ways. Health risks include but are not limited to depression, apathy, hallucinations, paranoia, and impaired judgment, and all substances have an adverse effect on pregnancy and the fetus. When two or more substances are combined, the effect is often stronger than their additive sum.

4.0 Local, State, and Federal Legal Sanctions

Local, state, and federal laws establish severe penalties for violations of drug and alcohol statutes. These sanctions, upon conviction, may range from a fine to life imprisonment. In the case of possession and distribution of illegal drugs, these sanctions could include the seizure and summary forfeiture of property, including vehicles. It is especially important to know that federal laws have established penalties for illegally distributing drugs to include life imprisonment and fines of up to $10,000,000.

4.1 Examples

- Unlawful possession of a narcotic drug is punishable by imprisonment in the state prison.
- The purchase, possession, or consumption of any alcoholic beverages (including beer and wine) by any person under the age of 21 is prohibited.
- It is illegal to provide alcohol to a person under the age of 21.
- Serving alcohol to an intoxicated person is prohibited.
- Selling any alcoholic beverages, except under the authority of a California Alcoholic Beverage Control License, is prohibited.
- It is a felony to induce another person to take various drugs and "intoxicating agents" with the intent of enabling oneself or the drugged person to commit a felony. The person who induced the other may be regarded as a principal in any crime committed.

- Any person found in a public place to be under the influence of an intoxicating liquor or drug and unable to care for their own safety, or who is interfering with the use of a public way, is guilty of disorderly conduct, which is a misdemeanor.
- It is illegal for a person to possess nitrous oxide (e.g., whippets) with the intent to inhale it for the purpose of altering their mood or mental functioning.

5.0 Resources for Staff, Faculty, Postdoctoral Scholars and Students

Caltech recognizes drug and alcohol abuse and dependency as treatable conditions and offers faculty, staff, postdoctoral scholars, and students support programs for individuals with substance use problems. Faculty, staff, and postdoctoral scholars are encouraged to seek assistance for drug- and alcohol-related problems through the Caltech Staff and Faculty Consultation Center (SFCC) at campus and the Employee Assistance Program (EAP) at JPL. Individuals can contact the SFCC by calling (626) 395-8360, and the EAP by calling (800) 367-7474. Students are encouraged to seek assistance from Student Wellness Services (SWS) at (626) 395-8331. In addition, faculty, staff, postdoctoral scholars, and students can seek confidential referral information through the Center for Inclusion & Diversity at (626) 395-6207.

The staff of the SFCC, the EAP, and SWS will help employees and students to identify appropriate treatment resources and will refer them to counseling, treatment, or rehabilitation programs, as appropriate. Health insurance plans provide varying amounts of coverage for substance-abuse programs to address substance abuse and rehabilitation. Individuals may contact their health providers or the Caltech Human Resources Benefits office at campus at (626) 395-6443, or JPL at (818) 354-4447, for plan details. Information obtained regarding a faculty, staff, postdoctoral scholar, or student during voluntary participation in services at the SFCC, EAP, SWS, or any related program will be treated as strictly confidential, and no information, including whether or not an individual is receiving services, will be shared with third parties, except by written consent or as required by law.

6.0 Drug and Alcohol Awareness Program

Caltech has established and will maintain a drug and alcohol awareness program to educate faculty, staff, postdoctoral scholars, and students about:

1. Caltech's substance abuse policy;
2. the dangers of drugs and alcohol in a work and academic environment;
   faculty, staff, postdoctoral scholar, and student assistance programs; and
3. disciplinary action that may be imposed on faculty, staff, postdoctoral scholars, and students for violations of this policy.

Caltech will distribute to all faculty, staff, postdoctoral scholars, and students a copy of this policy on an annual basis.

7.0 Supervisor's Responsibilities

If an employee is suspected of violating this policy, the employee's supervisor should consult with Employee and Organizational Development (EOD) at campus or the Employee Relations Department of the Human Resources Directorate at JPL regarding appropriate actions, which may include an investigation and discipline up to and including termination of employment. If a supervisor believes an employee's behavior raises safety concerns for the employee or others, the supervisor must take immediate action, including calling EOD on campus or the Employee Relations Department of the Human Resources Directorate at JPL, to assess and address the situation and to remove the employee from the worksite if necessary.

8.0 Caltech Sanctions

Caltech will impose sanctions for violations of or failure to comply with the requirements of this policy. These sanctions will be consistently enforced, and penalties will depend on the severity of the offenses. Penalties may include employment termination, student expulsion, being permanently banned from Caltech premises, and referral to law enforcement for the most serious violations of the law and this policy (e.g., the manufacture or distribution of banned substances). Disciplinary action may be invoked entirely apart from any civil or criminal penalties that the faculty, staff, postdoctoral scholars, and students might incur.

UNLAWFUL HARASSMENT, DISCRIMINATION, AND ABUSIVE CONDUCT

1.0 Policy

It is the policy of Caltech to provide a work and academic environment free of unlawful harassment ("harassment") and other abusive conduct.

2.0 Scope

This policy applies to all members of the Caltech community, including at JPL (students, faculty, supervisory and nonsupervisory employees, postdoctoral scholars, volunteers, interns, vendors, contractors, persons performing services under contract with Caltech, visitors, and any other individuals regularly or temporarily employed, studying, living, visiting, or otherwise participating in Caltech's employment and education programs and activities). This policy applies to conduct occurring on Institute-controlled property, at Institute-sponsored events and in Institute employment and education programs and activities, regardless of location.

3.0 Harassment

Harassment in education programs and activities means any unwelcome behavior (physical, verbal, graphic, or written) based on a protected characteristic, that, based on the totality of the circumstances, is subjectively and objectively offensive and that, from the perspective of a reasonable person in the complainant's position, it is so severe or pervasive that it limits or denies a person's ability to participate in or benefit from the Institute's education programs or activities.

A person can commit harassment without intending to create these outcomes. In evaluating the severity, persistence. or pervasiveness of the conduct, Caltech considers whether the target(s) of the conduct, as well as an objectively reasonable person considering the conduct from the perspective of the target(s) would find the conduct to be severe, persistent, or pervasive. Relevant factors for consideration may include, but are not limited to, the context, nature, scope, frequency, duration and location of the harassment based on the protected characteristic(s) of those involved. Generally, the less pervasive the harassing conduct, the more sever it must be to establish a hostile environment. In some instances, a single act may be sufficiently severe as to be prohibited by this policy.

Harassment in any form, based on any of the following protected characteristics and protected activities ("protected characteristics"), is unlawful and is strictly prohibited at all times, as are all forms of prohibited conduct set forth in the Sex Discrimination Policy:

- Race (includes hair texture and protective hairstyle, as well as ethnicity)
- Color
- Religion (includes religious dress and grooming practices)
- Sex/gender (includes pregnancy, childbirth, breastfeeding, and/or related medical conditions)
- Gender identity and gender expression
- Sexual orientation
- Marital status
- Medical condition (genetic characteristics, cancer, or a record or history of cancer)
- Military or veteran status
- National origin (includes language use and possession of a driver's license issued to persons unable to prove that their presence in the United States is authorized under federal law)
- Ancestry (including caste)
- Disability (mental and physical, including HIV/AIDS, cancer, and genetic characteristics)
- Genetic information
- Request for family care leave
- Request for leave for a serious health condition
- Request for pregnancy disability leave
- Domestic violence victim status
- Age (40 or older)
- Criminal background (Fair Chance Act)

- Any other factor protected by federal, state, or local laws
- Association with an individual who is in one of the foregoing protected characteristics
- Reproductive health care decision-making

Harassment in the employment environment may include, but is not limited to, these examples.

- Verbal, physical, and visual conduct that creates an intimidating, offensive, or hostile working environment, or that interferes with work performance, including conduct that denigrates or shows hostility or aversion toward an individual because of any protected characteristic.
- Visual or graphic images, such as offensive and/or sexually explicit posters, photographs, symbols, cartoons, drawings, computer displays, e-mails, text messages, objects, or digital and social media activity, including blogs, forums, chat rooms, social networking sites, and other social media applications.
- Physical conduct, including touching, physical assaults or threats, blocking someone's path or normal movement
- Sabotaging work product or performance.
- Unwanted sexual advances, invitations, or comments.
- Threats and demands to submit to sexual requests as a condition of continued employment or to avoid loss of employment benefits.
- Offers of employment benefits in return for sexual favors.
- Conversation about one's own or someone else's sex life, sex, gender, sexual orientation, gender nonconformity, and/or gender identity.
- Inappropriate conduct or comments consistently targeted at only one gender, race, or another protected characteristic.

Harassment in the educational setting also includes harassment based on protected characteristics that is contrary to the pursuit of inquiry and education. The following are examples of behaviors that may constitute harassment in the educational setting:

- a disabled individual is not included in an off-site outing because of lack of mobility;
- an individual is ostracized from group activities because of their national origin;
- a student posts racist jokes to a house email list.

Complaints concerning sex and gender-based discrimination and harassment and sexual misconduct are governed by the Sex Discrimination Policy.

Discrimination

Discrimination refers to the treatment of a person or persons adversely based on the person or person's protected characteristics. In the educational environment adverse treatment means actions which may have a substantial and material adverse impact on a

complainant's participation in education programs, activities, opportunities or benefits,. In the work environment adverse treatment includes, but is not limited to, hiring, firing, pay, job assignments, promotions, layoff, training, benefits and other terms or conditions of employment.

Minor or trivial actions or conduct, although frustrating or offensive, do not constitute adverse treatment.

Abusive Conduct

Some kinds of behavior that are clearly intended to harass (abusive conduct), while inappropriate and not tolerated at Caltech, may not constitute harassment but nevertheless violate Caltech policy. Abusive conduct, is malicious conduct occurring in a work or educational setting that a reasonable person would find hostile, offensive, and unrelated to Caltech's legitimate business or educational interests. Caltech may conduct an investigation or review of complaints of abusive conduct and take appropriate steps to address any abusive conduct that is found to have occurred.

Examples of abusive conduct may include:

- repeated infliction of verbal abuse, such as the use of derogatory remarks, insults, verbal epithets;
- physical conduct that can be considered threatening, intimidating, or humiliating;
- the gratuitous sabotage or undermining of a persons work performance;
- a single act shall not constitute abusive conduct, unless especially severe and egregious.

Caltech is committed to educating the community in ways to prevent harassment and abusive conduct. Caltech requires all employees, including those responsible for directing or supervising other Caltech employees or evaluating the work of students, to regularly participate in training regarding harassment, and the prevention of harassment and other abusive conduct, consistent with federal and state legal requirements.

Violation of an Institute Directive

Any individual may be found in violation for failure to comply with a Caltech directive regarding a supportive measure (e.g. violating the terms of a Mutual No-Contract Order).

Prohibition Against Retaliation

No one may intimidate, threaten, coerce, or discriminate against any individual for the purpose of interfering with any right or privilege secured by this policy or the related procedures, or because the individual has made a report or complaint, testified, assisted, participated, or refused to participate in any manner in nay action or process under this policy or the related procedures or Institute directives such as a no contact order. Intimidation, threats, coercion, or discrimination, for the purpose of interfering with any right under this policy or the related procedures constitutes retaliation. The rights and privileges secured under this policy and the related procedures include but are not limited to:

1. filing or assisting in the filing of a complaint or report of a suspected violation of this policy;
2. opposing any act or practice made unlawful by any federal, state, or local laws requiring equal opportunity;
3. participating, assisting, or otherwise cooperating in an investigation, compliance review, hearing, or any other activity related to a violation of this policy or administration of any federal, state, or local law requiring equal opportunity; and/or
4. exercising any legal right protected by federal, stat or local law requiring equal opportunity.

Complaints of retaliation will be addressed under the Procedures for Complaints of Unlawful Discrimination, Harassment and Retaliation.

The following actions do not constitute retaliation: the exercise of rights protected under applicable law or Caltech's charging an individual with a p9olicy violation for making a materially false statement in bad faith in the course of a resolution process. A determination that a respondent was or was not responsible for alleged misconduct alone is not sufficient to conclude that any party made a materially false statement in bad faith.

4.0 Reporting Complaints and Concerns

Caltech's ability to remedy harassment and abusive conduct and maintain an environment free of harassment and abusive conduct is limited if incidents are not reported. Anyone who witnesses, experiences, or is otherwise aware of conduct that they believe to be in violation of this policy, including retaliation, is urged to immediately report it, or to request assistance and guidance. Complaints or concerns about harassment should be reported to the Equity and Title IX Office or one of the offices listed below, at campus, or the Employee Relations Group at JPL. Reports may be made at any time. A delay should not discourage anyone from reporting harassment. Delayed reporting is better than no reporting. Reports may be made in writing or orally. Harassment complaints are addressed under the Procedures for Complaints of Sex Discrimination.

Complaints or concerns about abusive conduct (1) against a student should be reported to the appropriate dean, (2) against a staff member or postdoctoral scholar to Employee & Organizational Development (EOD), (3) against a faculty member to the appropriate Division Chair or the Office of the Provost, and (4) against a JPL employee to Employee Relations at JPL. In order to make an appropriate judgment as to whether incidents are appropriately investigated as harassment, discrimination, or abusive conduct, the full context in which the conduct occurred will be evaluated. Complaints are considered based on the totality of the facts and circumstances.

Members of the Caltech community are encouraged to err on the side of reporting any conduct they think may be harassment or abusive conduct covered under this policy, regardless of where the

incident occurred or who committed it. Even if Caltech does not have jurisdiction over the incident or the perpetrator, Caltech will take reasonable action to remedy the effects of the harassment or abusive conduct on the Caltech community and prevent any reoccurrence of the behavior.

Any employee in a supervisory role, including faculty, must promptly report **all** alleged harassment, abusive conduct, discrimination, gender-based misconduct, and retaliation, regardless of its alleged severity or frequency, to the Equity and Title IX Office at campus or Human Resources at JPL, which will provide guidance and advice. In addition, other employees qualifying as responsible employees under the Sex Discrimination Policy, must promptly report any instance of prohibited conduct to the Equity and Title IX Office or the Deputy Title IX coordinator for JPL, as appropriate.

If a member of the Caltech community would like support and guidance in filing a complaint, they may contact the assistant vice president for equity and equity investigations in the Equity and Title IX Office, JPL's manager of employee relations, or the JPL section manager of talent management or Human Resources Business Partners at JPL.

5.0 Anonymous Reporting

Caltech provides the following resources for anonymous reporting:

- Campus Hotline : (626) 395-8787 or (888) 395-8787
- Equity and Title IX Office Online Report a Concern Form: Online Report Form | Equity and Title IX Office (caltech.edu)
- JPL Ethics Hotline: (818) 354-9999
- JPL Protective Services Division's Workplace Violence Hotline: (818) 393-2851
- For either Campus or JPL by submitting a compliance Hotline Contact Form

If the reporting party wants to remain anonymous, they should not share any personally identifying information. If the reporting party does share such information, the Equity and Title IX Office will contact the reporting party with information about support resources and reporting options; if an investigation is pursued, the reporting party who identified themselves will be notified.

6.0 Contacting Outside Agencies

In addition, employees who believe they have been unlawfully harassed on the basis of a protected characteristic have the right to file a complaint with the federal Equal Employment Opportunity Commission or the California Civil Rights Department, which have the authority to remedy violations. Employees, students, and others participating in Caltech's educational programs and activities may file complaints with the U.S. Department of Education Office for Civil Rights (202) 607-1600, ocr.seattle@ed.gov, or (800) 421-3481 or OCR@ed.gov. Complaints may also be directed to the Bureau for Private Postsecondary Education at bppe.ca.gov/.

7.0 Investigation of Complaints

Caltech will conduct a fair, timely, and thorough investigation into or review of complaints as appropriate within the scope of this policy to determine what occurred and take reasonable steps to remedy the effects of any harassment or abusive conduct and prevent recurrence of the behavior. Complaints of harassment will be addressed under the Procedures for Complaints of Unlawful Discrimination, Harassment and Retaliation. Caltech provides all parties with appropriate due process and reaches conclusions based on the evidence collected. Caltech takes appropriate action, including disciplinary measures up to and including termination of employment, student expulsion, or being permanently excluded from Caltech-controlled premises, when warranted.

8.0 Privacy

Privacy means that information related to a report of harassment or abusive conduct will only be shared with those individuals who have a "need to know." The determination of who has a "need to know" is within the discretion of Caltech. These individuals are required to be discreet and respect the privacy of all individuals involved.

No meetings or conversations that take place under this policy or the Procedures for Complaints of Unlawful Discrimination, Harassment, and Retaliation may be audio-visually recorded by anyone.

9.0 Confidential Resources

Caltech offers members of the Caltech community the choice of seeking confidential counseling outside of Caltech's procedural mechanisms for resolving harassment and abusive conduct complaints. These confidential counseling services are intended for the personal benefit of the individual and offer a setting where various courses of action can be explored. Talking to any of these staff members does not constitute reporting an incident to Caltech.

Confidentiality generally means that information shared by an individual with designated campus or community professionals cannot be revealed to any other individual without the express permission of the individual. These professionals are listed below. They are prohibited from breaking confidentiality, when acting solely within the scope of their respective roles, unless there is an imminent threat of harm to self or others or as otherwise required or permitted by law. When a report involves suspected abuse of a minor under the age of 18, these confidential resources may be required by state law to notify child protective services and/or local law enforcement.

An individual who has experienced unlawful harassment and who first requests confidentiality may later decide to file a complaint with Caltech. Mental health professionals and other confidential resources listed below will provide the individual with assistance in filing a complaint if the individual wishes to do so.

Mental health professionals in the Student Wellness Services (SWS), Counseling Services, and the Staff and Faculty Consultation Center (SFCC) provide mental health counseling services to the

campus community. The JPL Employee Assistance Program provides mental health counseling services to the JPL community. They will not report any information about an incident to Caltech, including the Title IX coordinator, unless requested by their client. They can be contacted 24 hours a day/7 days a week at:

- Students: Student Wellness Services, Counseling Services: (626) 395-8331
  An after-hours counselor may be reached by calling Counseling Services' main number and pressing '2': (626) 395-8331
- Faculty, campus staff and postdoctoral scholars:
  Staff & Faculty Consultation Center: (626) 395-8360
  After hours via Security: (626) 395-5000
- JPL employees:
  Empathia (identify yourself as a JPL employee)
  www.mylifematters.com/ (Password: JPL): (800) 367-7474

Other Confidential resources are:
JPL Ombuds: (626) 437-1990

10.0 Equal Employment Opportunity Coordinators and Title IX Coordinator

Caltech has designated Equal Opportunity coordinators (EO coordinators) who are responsible for assisting with and coordinating the education and compliance efforts relating to equal opportunity and nondiscrimination laws and Caltech policies. The following individuals have been designated as EO coordinators: the provost is the coordinator for faculty; the assistant vice president for human resources is the coordinator for campus staff, postdoctoral scholars, and volunteers; the associate deans of students are the coordinators for undergraduate students and interns; the dean of graduate studies is the coordinator for graduate students and interns; and the manager for human resources at the Jet Propulsion Laboratory is the coordinator for employees, interns and volunteers assigned there.

The assistant vice president for equity and equity investigations, who manages the Equity and Title IX Office, also has been designated as Caltech's Title IX coordinator. The contact number is (626) 395-3132, email: equity@caltech.edu, or visit the office in Room 205, Center for Student Services.

11.0 Informational Resources

Information on unlawful harassment, as well as copies of Caltech's Nondiscrimination and Equal Employment Opportunity, Unlawful Harassment, Sex Discrimination, and Violence Prevention policies, are available from Caltech's Title IX coordinator and deputy coordinators; Human Resources, Student Affairs and Deans offices; the Caltech Center for Inclusion & Diversity (CCID); resident associates; the Staff and Faculty Consultation Center (SFCC); and Employee & Organizational Development at Campus; and Employee Relations and the Human Resources Business Partners at JPL. The policies are published in the Caltech Catalog and on the following Caltech

websites: Caltech Human Resources, JPL Human Resources, Equity and Title IX Office, and Student Affairs.

Related Policies and Procedures:

- Nondiscrimination and Equal Employment Opportunity Policy
- Procedures for Complaints of Unlawful Discrimination, Harassment and Retaliation
- Sex Discrimination Policy
- Procedures for Complaints of Sex Discrimination
- Violence Prevention Policy

VIOLENCE PREVENTION

1.0 Policy

It is the policy of Caltech to provide a safe and secure environment for all members of the Caltech community and to prohibit all forms of violence on its premises or in any of its programs or activities. Caltech promotes measures aimed at reducing incidents of violence and the management of situations that may lead to violence. All members of the Caltech community shall cooperate to maintain a safe environment and shall comply with this policy.

2.0 Scope

2.1 Prohibited Conduct

Caltech does not tolerate violence, threats of violence, child abuse, child neglect, or stalking on any Institute premises or in any Institute activity or program. Weapons are not permitted on Institute premises and at Institute activities and programs as set forth below other than by law enforcement or security personnel as authorized.

2.2 Reporting Violence

Any individual who experiences or observes a threat or act of violence, or a weapon on Institute premises or at an Institute activity or program must immediately notify Campus Security or JPL Protective Services Division, or law enforcement. An individual at a non-campus or non-JPL location must immediately notify local law enforcement.

Campus Security (626) 395-5000
JPL Protective Services Division (818) 393-3333

If an individual becomes aware of behavior that they find concerning, the individual should notify one of the following individuals or offices:

Employee's supervisor / management	
Campus Human Resources - Employee and Organizational Development	(626) 395-6382
Dean of Undergraduate Studies	(626) 395-6351
Dean of Graduate Studies	(626) 395-6346
Provost Office	(626) 395-6320

Assistant Vice President for Equity and Equity Investigations, Title IX Coordinator	(626) 395-3130
Campus Security	(626) 395-5000
Campus Hotline	(626) 395-8787 or (888) 395-8787
JPL Human Resources	(818) 354-4447
JPL Protective Services Division	(818) 354-3530
JPL Workplace Violence Hotline	(818) 393-2851
JPL Ethics Office - Anonymous Reporting	(818) 354-6338
JPL Ethics Help Line	(818) 354-9999 or (866) 405-7536

Caltech will handle all reports of violence in a confidential manner, with information released as determined to be appropriate by Caltech. Managers are required to immediately report any violation or suspected violation of this policy to Caltech Security, JPL Protective Services Division, Human Resources, the deans or the provost, whether the violation is observed on Institute premises or at any Institute activity or program. Caltech policy prohibits retaliation against any faculty, staff, postdoctoral scholar, student, or third party who, in good faith, reports a violation or suspected violation of this policy.

Caltech will not tolerate intentional false reporting of incidents. A good faith complaint that results in a finding of "no violation" is not considered a false report. However, when a complainant or third party is found to have fabricated allegations or to have given false information with malicious intent or in bad faith, they may be subject to disciplinary action.

2.3 Reporting Child Abuse or Child Neglect

Every member of the Caltech community who knows of or reasonably suspects child abuse or child neglect has a personal responsibility to report to Caltech Security or the JPL Protective Services Division immediately.

Certain members of the community—known as mandated reporters—have a legal responsibility to act. A mandated reporter is a Caltech employee who meets one of the following definitions:

(a) holds a job recognized by the State of California as one that is legally required to report child abuse or neglect no matter where it occurs; or (b) engages in duties that bring them into contact with children on a regular basis or who supervises those whose duties bring them into contact with children on a regular basis, and thus are required to report child abuse or neglect occurring on Caltech premises or at an official activity of, or program conducted by, Caltech. All athletic coaches, including assistant coaches and graduate assistants involved in coaching, are mandated reporters under part (a) of the definition above and must report child abuse or

neglect no matter where it occurs. Certain other professionals at Caltech, such as medical and mental health professionals, are also mandated reporters under part (a).

Mandated reporters must report child abuse and neglect whenever, in their professional capacity or within the scope of their employment, they observe or reasonably suspect it. A mandated reporter should reasonably suspect child abuse or neglect whenever "it is objectively reasonable … to entertain such a suspicion, based upon facts that could cause a reasonable person in a like position, drawing, when appropriate, on their training and experience, to suspect child abuse or neglect." (Penal Code § 11166(a)).

Mandated reporters have the additional responsibility to report immediately or as soon as practicably possible by telephone and to submit a written follow-up report within 36 hours of receiving information concerning the incident to the LA County Child Protection Hotline (800) 540-4000 (or from out of state (213) 639-4500) or to the Pasadena Police Department 911 (for emergencies) or (626) 744-4241 (for non-emergencies), or to another local police department. A Suspected Child Abuse Report (SCAR) can be completed online (where the initial report was made to the LA County Child Protection Hotline) at mandreptla.org/cars.web. Mandated reporters will be provided the opportunity for training by Caltech and must sign an "Employee Acknowledgement of Mandated Reporter Status."

2.4 Definitions

Acts of violence include any physical action, whether intentional or reckless, that harms or threatens the safety of another individual at Caltech.

A threat of violence includes any behavior that by its very nature could be interpreted by a reasonable person as intent to cause physical harm to another individual.

Child means a person under the age of 18 years.

Child abuse includes physical injury inflicted on a child by another person, serious endangerment of a child's physical or mental health due to injury by act or omission, sexual exploitation of a child (including sexual intercourse between a child under 16 years of age and a person 21 years of age or older), lewd or lascivious acts, and child molestation; and unlawful corporal punishment.

Child neglect includes negligent treatment or maltreatment of a child under circumstances indicating harm or threatened harm to the child's health or welfare.

Stalking is a course of conduct directed at an individual that would cause a reasonable person to fear for his or safety or the safety of others, or suffer substantial emotional distress. Course of conduct means two or more acts, including, but not limited to, acts in which the stalker directly, indirectly, or through third parties, by any action, method, device, or means, follows, monitors, observes, surveils, threatens, or communicates to or about a person or interferes with the person's property. Reasonable person means a reasonable person under similar circumstances and with similar identities to the victim.

Stalking that is sex or gender-based should be reported and will be handled pursuant to the Sex Discrimination Policy and applicable procedures. Stalking that is not sex or gender-based is covered by this policy. Making an audio or video recording of an individual without their consent is prohibited and may constitute stalking under this policy or the Sex Discrimination Policy.

Weapon is defined as a firearm, ammunition, BB or pellet gun, paintball gun, stun gun, compressed air gun, or any replica firearm, martial arts weapon, fireworks, explosives, dangerous or highly flammable chemicals, dirk, dagger, ice pick, or knife having a blade longer than 2 1/2 inches (except for a knife or ice pick used for food preparation or consumption or for a lawful use in or around a residence), razor with an unguarded blade, razor blade, or box cutter (except for a razor, razor blade or box cutter for lawful use in a residence), or any object when used in a manner or under a circumstance that potentially may or does result in an act of violence or threat of violence.

An object otherwise defined above as a weapon is excepted when used for a lawful purpose within the scope of the person's employment or academic activities when approved by Caltech.

2.5 Investigating Prohibited Conduct

Reports of conduct that may violate any aspect of this policy will be taken seriously, properly investigated, and dealt with accordingly. Individuals who are found to have violated this policy may be subject to disciplinary action up to and including termination of employment, student expulsion, or being permanently excluded from Caltech-controlled premises. Additionally, when such acts potentially violate state or federal laws, the matter may be referred to law enforcement agencies for investigation.

3.0 Workplace Violence Prevention Plan

Both the Caltech campus and JPL have instituted Workplace Violence Prevention Plans consistent with California law.

The Caltech Chief of Campus Security and Parking Services is responsible for implementing the campus Workplace Violence Prevention Plan.

The Division Manager, Protective Services Division, is responsible for implementing the JPL Workplace Violence Prevention Plan.

4.0 Resources

The Staff and Faculty Consultation Center and the Student Counseling Center at campus or Empathia/Life Matters at JPL may provide resources such as intervention, consultation, or referral for clinical evaluation or treatment, including arranging for counselors to work with at-risk individuals and victims and observers of an incident. In addition, training is available from Human Resources regarding violence prevention, public safety awareness, and child abuse.

Contact information for these and other resources are:

Campus Staff and Faculty Consultation Center	(626) 395-8360
Human Resources-EOD	(626) 395-6382
JPL Human Resources	(818) 354-4447
Empathia/Life Matters	(800) 367-7474

Related Policies

- Unlawful Harassment and Abusive Conduct Policy
- Procedures for Complaints of Unlawful Discrimination, Harassment and Retaliation
- Sex Discrimination Policy
- Procedures for Complaints of Sex Discrimination
- Workplace Violence Prevention Plan for Caltech campus
- Workplace Violence Prevention Plan for JPL
- Reporting Workplace Threats and Unauthorized Firearms or Weapons (JPL)

Whistleblower Policy

1.0 Policy

It is important to Caltech that employees disclose violations or potential violations of law or other serious breaches of conduct without the fear of retaliation. Caltech policy prohibits retaliation against an individual who makes a good faith disclosure of suspected wrongful conduct. Any individual who engages in retaliation in violation of this policy will be subject to disciplinary action up to and including termination of employment or permanent separation from Caltech.

It is Caltech's policy to comply with applicable laws and regulations, including California's whistleblower law protections provided under Labor Code Section 1102.5 and the whistleblower rights and remedies provided under 41 USC Section 4712, which are summarized at Enhancement of Employee Whistleblower Protection. As employees of Caltech, each individual is responsible for making sure their conduct fully complies with all laws and regulations as well as Institute policies. Caltech expects employees with knowledge of specific acts that they reasonably believe violate the law or Caltech policy to disclose those acts to an appropriate Caltech official.

2.0 Reporting

An employee who becomes aware of any inappropriate or improper activity, or who believes they have been the subject of retaliation for making a good faith disclosure, is encouraged to contact their supervisor or one of the following offices: Human Resources, JPL Ethics Office, Audit Services and Institute Compliance (ASIC), or the Office of General Counsel. Anyone with questions or concerns regarding inappropriate or improper activities within Caltech may use one of the anonymous reporting mechanisms outlined below.

Web Hotline:
http://hotline.caltech.edu/
Telephone Hotline:
(626) 395-8787 or toll free (888) 395-8787
Interoffice Mail:
Audit Services and Institute Compliance, MC 250-64
U.S. Mail:
Audit Services and Institute Compliance
1200 E. California Blvd, MC 250-64, Pasadena, CA 91125
JPL Ethics Line:
(818) 354-9999 or toll free (866) 405-7536

WHISTLEBLOWER POLICY

1.0 Policy

It is important to Caltech that employees disclose violations or potential violations of law or other serious breaches of conduct without the fear of retaliation. Caltech policy prohibits retaliation against an individual who makes a good faith disclosure of suspected wrongful conduct. Any individual who engages in retaliation in violation of this policy may be subject to disciplinary action up to and including termination of employment, student expulsion, or being permanently excluded from Caltech-controlled premises.

It is Caltech's policy to comply with applicable laws and regulations, including California's whistleblower law protections provided under Labor Code Section 1102.5 and the whistleblower rights and remedies provided under 41 USC Section 4712, which are summarized at Enhancement of Employee Whistleblower Protection. As employees of Caltech, each individual is responsible for making sure their conduct fully complies with all laws and regulations as well as Institute policies. Caltech expects employees with knowledge of specific acts that they reasonably believe violate the law or Caltech policy to disclose those acts to an appropriate Caltech official.

2.0 Reporting

An employee who becomes aware of any inappropriate or improper activity, or who believes they have been the subject of retaliation for making a good faith disclosure, is encouraged to contact their supervisor or one of the following offices: Human Resources, JPL Ethics Office, Audit Services and Institute Compliance (ASIC), or the Office of General Counsel. Anyone with questions or concerns regarding inappropriate or improper activities within Caltech may contact one of these offices or may submit an anonymous report using one of the anonymous reporting mechanisms outlined below.

Web Hotline:
hotline.caltech.edu/
Telephone Hotline:
(626) 395-8787 or toll free (888) 395-8787
Interoffice Mail:
Audit Services and Institute Compliance, MC 234-06

U.S. Mail:
Audit Services and Institute Compliance
1200 E. California Blvd, MC 234-06, Pasadena, CA 91125
Campus Human Resources:
Kasey Byrne-Lowenthal, Senior HR Compliance Specialist
(626) 395-1952
JPL Ethics Line:
(818) 354-9999 or toll free (866) 405-7536

3.0 Anonymous Reporting
Caltech provides the following resources for anonymous reporting:

- Campus Hotline: (626) 395-8787 or (888) 395-8787
- JPL Ethics Hotline: (818) 354-9999
- JPL Protective Services Division's Workplace Violence Hotline: (818) 393-2851
- For either Campus or JPL by submitting a compliance Hotline Contact Form

A report is considered anonymous if the reporting party does not share their name or contact information. If a reporting party chooses to provide their name or contact information, the report will not be treated as anonymous and they will receive information about support resources, reporting options, and notification of an investigation, if an investigation is pursued.

PROCEDURES FOR COMPLAINTS OF UNLAWFUL HARASSMENT, DISCRIMINATION, AND RETALIATION

1.0 Introduction
Caltech will take prompt and appropriate action to address all reports of unlawful discrimination, harassment, and retaliation in accordance with these and related procedures. Caltech takes all such reports seriously and responds appropriately.

These procedures apply to the following:

At Campus and JPL, these procedures apply to allegations of unlawful discrimination, harassment, discrimination, and retaliation that are not covered under Caltech's Sex Discrimination Policy and Procedures for Complaints of Sex Discrimination Procedures.

A member of the Caltech community who wishes to report unlawful discrimination, harassment, or retaliation should do so as soon as possible, although reports (hereinafter "complaints") may be made at any time. Complaints can be made orally or in writing. Complaints should be brought to the attention of the Title IX Coordinator or one of the individuals designated in the Unlawful Harassment, Discrimination and Abusive Conduct Policy.

Any reference to a Caltech administrator in this document is understood to include not only that administrator but also their designee.

2.0 Complaint

Complaints of discrimination, harassment, and retaliation can be reported to the individuals designated in the Unlawful Harassment and Abusive Conduct Policy.

Consistent with Caltech's Unlawful Harassment, Discrimination, and Abusive Conduct Policy, Caltech will conduct a fair, timely, and thorough investigation into complaints within the scope of this policy to determine what occurred and take reasonable steps to remedy the effects of any harassment and prevent reoccurrence of the behavior. Caltech provides all parties with appropriate due process and reaches conclusions based on the evidence collected. Caltech takes appropriate action, including disciplinary measures, when warranted.

The complainant and the respondent may object to an investigator/s assigned to a complaint only on the basis that the investigator has a conflict of interest or cannot be impartial. Objections must be made to the Equity and Title IX Officer on campust or the Human Resources Office at JPL within three business days of being informed of the investigator/s. The Equity and Title IX Office on campus or Human Resources at JPL will consider any objections and notify the parties of the decision related to the investigator/s. Such objections must be made in writing to the Equity and Title IX Office on campus or to the manager of Employee Relations at JPL and must include the reason for the objection.

At any time, Caltech may put in place supportive or interim measures as appropriate to support the complainant, the respondent and/or others. Caltech may also explore informal resolution options to resolve the matter.

3.0 Investigative Steps

- The complainant and respondent will be provided with a copy of the Nondiscrimination and Equal Employment Opportunity policy, the Unlawful Harassment, Discrimination and Abusive Conduct policy, the Sex Discrimination Policy, and/or these procedures, as appropriate.
- Within a reasonable length of time after the complaint has been reported, the complainant and the respondent will each be notified of the allegations to be investigated.
- The complainant and respondent will be informed that Caltech does not tolerate retaliation, takes steps to prevent retaliation, and takes strong responsive action if retaliation occurs. The complainant and respondent will be advised to notify Caltech immediately if retaliation occurs.
- The investigation will be treated as private to the extent possible. Caltech will make reasonable and appropriate efforts to preserve the complainant's and respondent's privacy and protect the confidentiality of information but may need to share information on a need-to-know basis.
- Parties may not engage in coercion, pressure, undue influence, or retaliation with respect to potential witnesses or other parties in the course of preparing to meet with and providing evidence to the investigator. Parties may seek guidance from the Title IX

Coordinator and the investigator on appropriate communications. Communications between parties and witnesses deemed to have resulted from coercion, pressure, undue influence, or retaliation may be discounted altogether by the investigator or may be considered by the investigator in making credibility determinations and weighing evidence deemed subject to the undue influence.

- The investigation and adjudication of alleged prohibited conduct under this section is not an adversarial process between the complainant, the respondent, and the witnesses, but rather a process by which Caltech complies with its obligations under existing law and determines whether the allegations are substantiated by a preponderance of the evidence.
- The complainant and the respondent will be given an opportunity to be interviewed regarding the allegations and may suggest witnesses or information to the investigator/s, who will determine whether the suggestions are relevant, appropriate, or necessary to resolve disputed-fact issues. The investigator/s may also review other information and interview others they determine may have information relevant to investigating and resolving the complaint.
- Failure to cooperate with investigations or processes under these procedures, may also be a separate violation of this policy.
- Legal counsel and other advisers or support persons are not permitted to be present during interviews. Investigatory meetings will not be recorded by any party involved in a case.
- Complaints will be investigated and resolved within a reasonably prompt time frame after the complaint has been made, though factors, including but not limited to the complexity of the case, may impact the duration of the investigation. It is within the discretion of the Title IX Coordinator or Human Resources at campus, or the Manager of Employee Relations at JPL, to determine whether to conclude an investigation without further opportunity to provide evidence by a party or witness who fails to cooperate reasonably and timely in providing evidence (e.g., failing to schedule or appear for meetings, failing to provide evidence they said they would provide, failing to respond to communications from the investigator in a timely manner).
- The investigator/s will use the preponderance of the evidence standard in reaching findings and conclusions. A preponderance of the evidence means that it is more likely than not that the alleged misconduct occurred or did not occur.
- The investigation will not require, allow, rely upon, or use questions or evidence that constitute or seek the disclosure of information protected under a legally recognized privilege (e.g., attorney-client, doctor-patient, clergy-penitent), unless the person holding such privilege has waived the privilege.
- The investigator/s will reach findings and conclusions in the case, regarding whether the allegations are substantiated by a preponderance of the evidence, based on the facts available at the time of the decision and will report these to the appropriate

administrator ("decision maker") who will decide responsive measures, including any appropriate discipline. The appropriate decision makers are the following: the appropriate manager or supervisor for Campus and JPL staff and employee respondents; the Vice Provost for Research or Administration for faculty respondents; and the appropriate dean for student respondents.

- The complainant and the respondent will be notified of the outcome of the process in writing. The Notice of Investigation Outcome will include: a summary If the allegations; that the preponderance of the evidence standard was employed; a determination as to whether the Policy has been violated; the right to Appeal and Appeal procedures; and any other Remedies (if applicable) afforded to the Parties. The notice will usually be delivered electronically.
- Either party may submit an appeal of the outcome, in accordance with Section 6.0 below.
- Exceptions to or modifications of these procedures can be made by the Associate Vice President for Human Resources at campus or the Director for Human Resources at JPL, or their designee.

Investigative files are confidential and will be maintained in a file separate from an individual's personnel or student file. Disciplinary action taken against an employee as a result of an investigation will be included in the personnel file.

4.0 False Reports or Statements

Caltech expects its members to act with honesty, sincerity, and good faith in reporting concerns under this policy. Caltech will not tolerate intentional false reporting of information, allegations, or evidence. A good faith complaint that is not substantiated by a preponderance of the evidence after an investigation is not considered a false report.

However, when a party or witness is found to have intentionally fabricated or knowingly misrepresented information, allegations, or evidence, or otherwise to have acted with an intent to deceive or mislead in any of their dealings relating to Caltech's administration of this policy, they may be subject to disciplinary action, up to and including termination or expulsion.

5.0 Resolution

The conclusions that the investigator/s might reach, include but are not limited to:

A violation of Institute policy or other inappropriate conduct occurred.

- Inappropriate conduct occurred, but it did not constitute a violation of Institute policy.

For example, the respondent used poor judgment.

- The allegations were not supported by the preponderance of the evidence.

- The allegations were brought in bad faith.

If appropriate, the decision maker(s) will review the findings, conclusions, and recommendations, and determine appropriate actions in consultation with the investigating office (Equity and Title IX Office at Campus, Human Resources at JPL). Both the complainant and the respondent will be informed of the findings and notified when appropriate action has been taken.

If a violation of Institute policy or other inappropriate conduct occurred, appropriate corrective action will be taken. Depending on the severity of the case, possible corrective actions include verbal counseling, a formal written warning, removal from a supervisory position, and, in appropriate cases, termination of employment or expulsion.

Caltech will also take any necessary steps to protect the complainant from retaliatory actions by the respondent and/or others.

If it is determined that the allegations were brought in bad faith, appropriate action will be taken to address the situation.

Both the complainant and the respondent will be notified concurrently in writing of the results of the investigation, their right to appeal and the procedures for appeal. Privacy considerations prevent Caltech from informing a complainant of any sanctions or other remedies imposed against a respondent.

6.0 Appeals of Investigation Outcomes

- Appeals by either party must be in writing, no more than five pages in length, and submitted within ten (10) calendar days of notification of the decision. Appeals of decisions resulting from the investigation process must be on the grounds that a procedural error occurred that would have significantly affected the outcome of the investigation, or there is new evidence which would have significantly affected the outcome that was not available at the time of the proceeding. A procedural error is an error in how the investigation was conducted. A respondent also may appeal on the ground that the sanction is substantially disproportionate to the findings. In appeals on the ground that there is new evidence which would have significantly affected the outcome that was not available at the time of the proceeding, the party appealing should provide the new evidence and an explanation of why the evidence was not available during the investigation. Appeals that are not based on one or more of these grounds will not be considered and will be denied. Appeal decisions are final.
- Decisions regarding a faculty respondent may be appealed to the Office of the Provost. Decisions regarding a staff respondent, including post docs, may be appealed to the Assistant Vice President for Human Resources. Decisions regarding student respondents may be appealed to the Vice President of Student Affairs. Decisions regarding employees at JPL may be appealed to the Director of Human Resources at JPL. Decisions of the appropriate dean for students may be appealed to the Vice

President for Student Affairs.

7.0 Further Complaints
The complainant should immediately report if the corrective action does not end the unlawful discrimination or harassment, or if new or continuing unlawful discrimination or harassment occurs. In such cases, the complainant has the right to file another complaint.

8.0 Distribution of the Procedures
These procedures will be distributed annually to faculty, staff, and students, and upon arrival to faculty, staff, or student newcomers to Caltech. In the event that any significant revisions are made, revised versions will be distributed.

9.0 Exceptions
Exceptions to or modifications of these procedures can be made by the associate Vice President for Human Resources at campus or the Director for Human Resources at JPL.

Related Policies and Procedures:
- Nondiscrimination and Equal Employment Opportunity Policy
- Unlawful Harassment and Abusive Conduct Policy
- Sex Discrimination Policy
- Procedures for Complaints of Sexual Misconduct Under Title IX and the California Education Code
- Violence Prevention Policy

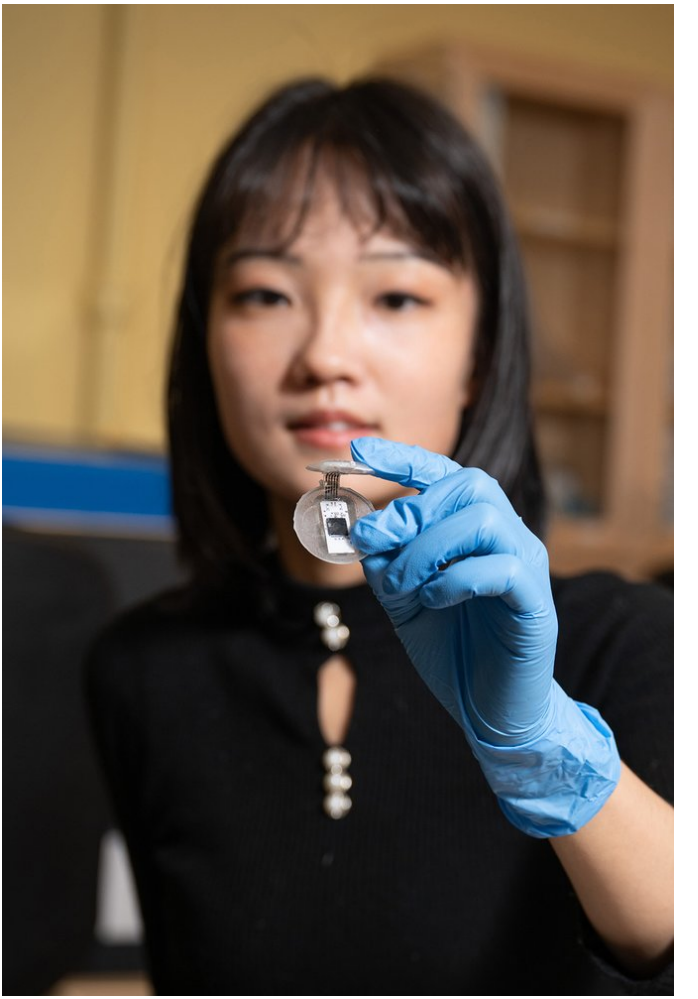
STUDENT AFFAIRS POLICIES

In addition to the Institute Policies listed above, there are a number of Student Affairs policies, procedures and guidelines on the Student Affairs website:

- Alcohol and Other Drugs
- Fire Safety
- Good Samaritan
- Hazing Prevention Policy
- LN2 Policy and Protocols
- Missing Person
- Mural Policy in Caltech Housing
- PNG Policy
- Student Problem-Resolution Process

For the text of the full policies, please see the Student Affairs website at studentaffairs.caltech.edu/policies.

Areas of Study and Research



AEROSPACE

The Guggenheim Aeronautical Laboratory, the Kármán Laboratory of Fluid Mechanics and Jet Propulsion, and the Firestone Flight Sciences Laboratory form the Graduate Aerospace Laboratories, widely known as GALCIT. In this complex are housed the solid mechanics, impact mechanics, and deployable space structures laboratories, the hypersonics and hydrodynamics facilities, the explosion dynamics and detonation physics laboratories, and the Joe and Edwina Charyk Laboratory of Bioinspired Design and Biopropulsion, the Center for Autonomous Systems and Technologies, as well as the various disciplines making up the broad field known as aerospace.

AREAS OF RESEARCH

Aerospace has evolved at Caltech from a field of basic research and engineering, primarily related to the development of the airplane, into a wide discipline encompassing a broad spectrum of basic as well as applied problems in fluid dynamics and mechanics of solids and materials and design and control of autonomous systems. Educational and research thrusts include the application of mechanics to various aspects of space exploration and to the study of biosystems and biopropulsion. Research at GALCIT has traditionally pioneered exploration of areas that have anticipated subsequent technological demands. This tradition places a high premium on in-depth understanding of fields both closely and remotely related to the behavior of fluids, solids, combustion, materials, and structures, such as physics, applied and computational mathematics, dynamical systems, earthquake physics, atmospheric studies, materials science, micro- and optoelectronics, microfluidics, bioinspired design, biomedical devices, and even astrophysics. GALCIT students are known and sought after for their broad yet intense education and for their ability to deal with new and challenging problems.

Major areas of experimental, theoretical, and numerical research currently pursued by aerospace students at Caltech are briefly described below.

- *Mechanics of Lightweight Space Structures.* Current efforts in the field of next-generation deployable space structures aim to increase reliability and also lower fabrication and assembly costs by moving toward structures that consist of only a small number of separate pieces able to undergo large elastic deformations. These elastic–stored-energy structures return to their original, unstressed configuration when they are released in orbit. The design of these structures requires accurate structural models that incorporate geometry change and contact effects in sufficient detail to capture the actual behavior that is observed in ground tests. Local and global instabilities are often observed during folding/deployment, and their effects can also be very important. Ultimately, validation against space-based experiments will be pursued for a selected number of structural configurations. In parallel to these studies, thermomechanical

constitutive models for ultrathin composite materials for these novel deployable space structures are being developed. Extensive studies of the deployment, elastic, and viscoelastic stability of stratospheric balloons are also being conducted.

- *Physics of Fluids.* Fluid dynamics as a discipline is as much a part of physics as of engineering. Physics of fluids refers to research in areas closer to applied physics than to direct technical applications. Present active research includes studies in gas dynamics and hypervelocity flows, diffraction and focusing of shock waves, detonation waves, shock-induced Rayleigh-Taylor and Richtmeyer-Meshkov instabilities, transient supersonic jets, the development of laser-scattering diagnostic techniques for fluid-flow measurements, the study of structures and mechanics in transition and turbulence, studies of two-phase flows and turbulent mixing, chemically reacting flows, and experimental manipulation and control of wall-bounded flows for improved flow characteristics, such as reduction of drag, noise, and structural loading.
- *Physics of Solids and Mechanics of Materials.* Mechanics of materials research involves both the quasi-static and dynamic characterization of the mechanical behavior and failure of solids. In order to understand materials for applications in a wide range of structures germane to aerospace as well as other engineering disciplines, both the physical foundations of that behavior and the mathematical or numerical representation of such behavior needs to be understood. Accordingly, studies involve material response at both the macroscopic (continuum) scales and the micro- and nanoscales. Of interest are the typical engineering metals, multiphase (composite) materials, polymers and ceramics, thin film materials used in microelectronic and optoelectronic applications, soft tissue mechanics of materials, and active materials used in structural actuation and controls. Other areas of active research include the study of highly nonlinear dynamics in solids, multiscale acoustic metamaterials, the analysis and design of mechanical metamaterials for the extreme conditions in air and space applications, and nondestructive evaluation/structural health monitoring of structures.
- *Space Technology.* The goal of industrial utilization and exploration of space requires that one addresses a wide range of engineering problems. Examples of research activities include lightweight structures for large aperture systems, in-space manufacturing, material and structural behavior in extreme temperature and radiation environments, spacecraft shielding against hypervelocity impact threats, the mechanics of sample containment for planetary protection, low-g biomechanics, biomimetics of locomotion in planetary atmospheres, hypersonic reentry into planetary atmospheres, in-space propulsion, guidance, navigation and control, and launch-vehicle performance and safety. Opportunities exist for research in collaboration with the Jet Propulsion Laboratory.

- *Computational Solid Mechanics.* Computational solid mechanics addresses phenomena ranging from the atomistic scale, e.g., nanostructured materials or nanoscale structures and devices, to the structural scale, e.g., fracture of aircraft or spacecraft components, modeling of large space structures or even dynamic fragmentation phenomena accompanying hypervelocity impact. It provides an indispensable tool for understanding the relation between structure and mechanical properties of materials, for predicting the efficiency of such industrial processes as machining and metal forming, and for assessing the safety of such structures as airplanes, spacecraft, automobiles, and bridges. The goals and objectives of this activity are to provide a state-of-the-art environment for the development of numerical methods in solid mechanics, to provide the computational resources required for large-scale simulations in solid mechanics, and to serve as an instructional facility for advanced courses.
- *Computational and Theoretical Fluid Dynamics.* Many of the fluid dynamics phenomena studied experimentally at GALCIT are also being investigated by numerical simulation and by theoretical analysis. Present active research areas in computational and theoretical techniques include direct numerical simulation, particle methods for flow simulation, new algorithms and subgrid-scale models for compressible and incompressible flows, large-eddy simulation methods, flows with shocks and driven by shocks, analytical and computational techniques for turbulence structure diagnostics, analysis of turbulent mixing dynamics, high-explosive interactions with deformable boundaries, chemically reacting flows, and detailed chemical reaction kinetics in flames and detonations.
- *Mechanics of Fracture.* An active effort is being made to understand mechanisms in a wide range of fracture problems. Aspects that are studied include quasi-static and dynamic crack growth phenomena in brittle and plastically deforming solids, polymers and advanced composites, as well as fatigue and failure of adhesive bonds. Research areas adjunct to dynamic fracture studies are those of dynamic localization in metals and of failure in frictional interfaces. These include the study of shear rupture phenomena in both coherent and incoherent interfaces. The dynamic failure of modern composite and layered materials and the phenomenon of earthquake rupture growth along geological faults have motivated these studies.
- *Aeronautical Engineering and Propulsion.* Research in the aeronautical engineering area includes studies of airplane trailing vortices and separated flows at high angles of attack. Research work in the propulsion area has centered on the fluid dynamic problems associated with combustion, solid propellant rocket motor instabilities, fluid dynamics and optimization of scramjets, and pulse detonation engines.
- *Biomechanics of Fluids and Solids.* The kinematics and dynamics of fluid flows in biological systems are studied in experiments, numerical simulations, and theoretical analyses. These flows are

often characterized by unsteady vortex dynamics, coupled fluid interactions with flexible material surfaces, non-Newtonian fluid behavior, and, in some cases, compressibility. Areas of active research include animal swimming and flying, cardiovascular fluid dynamics and hemodynamics, the mechanics of morphing/active deformable surfaces for flow control, and biologically inspired design of engineering systems.

- *Technical Fluid Mechanics.* These areas are related to a variety of modern technological problems and, in addition, to the traditional aeronautical problems of drag, wing stall, and shear flow mixing. Additional areas of activity include bluff-body aerodynamics, fluid-structure interaction, turbulent combustion, laminar diffusion flames and their instabilities, explosions, hydrodynamics and two-phase flows, interaction of vorticity with free-surface, cardiac flows, swimming and flying, and active and passive control of transition and turbulence. Acoustics problems studied include jet noise, combustion noise, and instabilities such as the generation of organ pipe oscillations in large burners of electric generating plants.
- *Fluid Mechanics, Control, and Materials.* The effects of boundary conditions on turbulence characteristics and general flow physics, scaling and controllability are investigated using interdisciplinary methods based on developments in materials science and control techniques. Experimental manipulation of canonical and simple model flows is used to probe fundamental issues of flow physics and control.
- *Autonomous Systems and Technologies.* Interdisciplinary research in the expanding area of autonomous systems involves, but are not limited to, drones, robots, and spacecraft for use in science, exploration, and transportation. The research addresses sensing, control, vision, machine learning, and other emerging areas. Advanced drone research, autonomous exploration, and swarm robotics will draw research from the full range of engineering at Caltech, the geological and planetary sciences division, and JPL.

PHYSICAL FACILITIES

The Graduate Aerospace Laboratories contain a diversity of experimental facilities in support of the programs described above. The Cann Laboratory is a teaching facility utilized for graduate and undergraduate experiments in fluid and solid mechanics. Low-speed wind tunnels include the John W. Lucas Adaptive Wall Tunnel, the Merrill Wind Tunnel, and special-purpose flow facilities. Smaller water channels and a tow tank for studies of wave motion and flow visualization are also available. For investigations of high-speed flows, there is a Ludwieg tube, a supersonic shear layer facility, a hypervelocity expansion tube, and the T5 shock tunnel for studying hypervelocity gas flows up to 7 km/s. Shock tubes and other special facilities are available for the study of extreme temperatures, shock waves, deflagrations, detonations acoustics, and combustion at variable pressure conditions.

The Center for Autonomous Systems and Technologies (CAST) contains an 85-foot track for walking robots and a wholly enclosed 75,000 cubic foot aerodrome for drone testing which is the tallest of its kind. Environmental simulation is provided by a 100-square-foot wall comprised of 1,296 fans capable of generating wind speeds of up to 44 mph, along with a side wall of an additional 324 fans, all of which can be individually controlled to create a nearly infinite variety of conditions.

The solid and structural mechanics laboratories contain standard as well as special testing facilities for research related to aircraft, deployable space structures, and failure/fracture behavior of materials under static and dynamic loads, including three servo-hydraulic facilities, two of which operate on a "tension/torsion'' mode, and a nanoindenter. A range of digital and film high-speed cameras offering recording at rates up to 100 million frames per second are available for the study of fast phenomena, such as wave propagation, hypervelocity impact, and the mechanics of static and dynamic fracture. Dynamic testing facilities include specialized electromagnetic loading devices (stored energy ~120 kJ), a drop weight tower, split Hopkinson bars (axial/torsional), and plate impact apparatus. Diagnostic devices include full-field interferometric and high-speed temperature measurements, both for static and dynamic applications. Other specialized facilities include a Class One clean room area that houses microelectronic wafer inspection metrology tools, and the Small Particle Hypervelocity Impact Range (SPHIR) jointly operated with JPL, which is capable of launching micrometeoroid surrogate particles at speeds up to 8 km/s. Facilities are available for scanning microscopy (AFM, STM) and electromechanical characterization of materials.

Other assets include state-of-the-art electronic instrumentation and computer systems for real-time control of experiments, data acquisition, processing, storage, and digital image processing. Computational facilities include powerful workstations, on-campus high-performance computing machines, and remote supercomputers such as those generally available at NSF, NASA, and DOE centers. Graphics workstations are available to support research in computational fluid dynamics and solid mechanics.

APPLIED AND COMPUTATIONAL MATHEMATICS

An interdisciplinary program of study in applied and computational mathematics that leads to the Ph.D. degree is offered by the Computing & Mathematical Sciences department. In addition to various basic and advanced courses taught by the applied and computational mathematics faculty, broad selections are available in mathematics, physics, engineering, and other areas. Students are expected to become proficient in some special physical or nonmathematical field. A subject minor in applied computation is

offered jointly with the computer science option.

In addition to the applied and computational mathematics faculty, professors from other disciplines such as mathematics, physics, engineering, and biology supervise research and offer courses of special interest. The applied and computational mathematics group has access to supercomputers and concurrent computers.

The present graduate program is one leading mainly to the Ph.D. degree. The curriculum consists of two types of courses: those that survey the methods used in applied and computational mathematics, and those that have a special applied and computational mathematics flavor and represent active research interests of the members of the faculty. Among the latter have been wave motion, perturbation theory, fluid mechanics, optimization, stochastic processes, wavelet analysis, signal processing, numerical analysis, computational electromagnetism, computational fluid dynamics, mathematics of data science, probability, random matrix theory, applied algebraic geometry and statistical inference, game and decision theoretic approaches to numerical approximation and learning, homogenization, multifidelity and multiscale analysis, and stochastic modeling, stochastic analysis, data assimilation, and inverse problems. Through study outside of applied and computational mathematics, each student is expected to become competent in some special physical or nonmathematical field. In this way, subjects for research appear naturally, and a broad educational program is provided.

The group primarily interested in applied and computational mathematics currently consists of approximately 25 students and eight professors. Also, each year many distinguished visitors come either to present lectures or remain in residence for large parts of the academic year.

AREAS OF RESEARCH

Research is particularly strong in theoretical and computational fluid mechanics, theoretical and computational materials science, computational electromagnetism, numerical analysis, ordinary and partial differential equations, multi-scale analysis, geometric integration, integral equations, linear and nonlinear wave propagation, water waves, bifurcation theory, perturbation and asymptotic methods, stability theory, variational methods, approximation theory, uncertainty quantification, randomized algorithms, continuous optimization, discrete optimization, statistical estimation, computational harmonic analysis, stochastic processes, signal and imaging processing, inverse problems, mathematical biology, large-scale scientific computing, mathematics of data science, and probability and random matrix theory, game and decision theoretic approaches to numerical approximation and learning, homogenization, multifidelity and multiscale analysis, and stochastic modeling and stochastic analysis, data assimilation, inverse problems, and related branches of analysis.

APPLIED MECHANICS

AREAS OF RESEARCH

Advanced instruction and research leading to degrees of Master of Science and Doctor of Philosophy in applied mechanics are offered in such fields as elasticity; plasticity; wave propagation in solid media; mechanics of quasi-static and dynamic fracture; dynamics and vibrations; finite element analysis; and stability, control, and system identification of mechanical and structural systems. Research studies in these areas that illustrate current interests include linear and nonlinear random vibrations of uncertain dynamical systems; structural dynamics and control for earthquake and wind loads; linear and nonlinear problems in static and dynamic elasticity, plasticity, and viscoelasticity; computational mechanics; mechanics of time-dependent fracture; chaotic behavior of dynamical systems; and material instabilities and phase transformations in solids.

PHYSICAL FACILITIES

See Mechanical Engineering and Civil Engineering.

APPLIED PHYSICS

The Applied Physics option was instituted in 1970 in order to provide an interdivisional program for undergraduate and graduate students at Caltech interested in the study of both pure and applied physics. The small size of Caltech, coupled with its strength in the basic sciences and engineering, has made it possible for faculty and students alike to pursue wide-ranging interests in the application of modern physics to the development of new technology. Research efforts in applied physics are driven by a fundamental understanding of the physical principles underlying applications and a strong motivation to use this knowledge to invent new experimental techniques, processes, devices and materials. Core and affiliate faculty spanning several divisions on campus participate in instruction and research leading to B.S., M.S., and Ph.D. degrees in applied physics.

This program is designed for undergraduate and graduate students who wish to expand their training beyond the study of fundamental physics to include research and development of real-world applications. The training helps develop a solid foundation in physics through introductory courses in classical physics, classical electrodynamics, quantum mechanics, thermodynamics, statistical mechanics, and mathematical physics. More advanced training is provided through coursework and research activities in solid state physics, electromagnetic wave propagation, optoelectronic materials and devices, transport phenomena in hydrodynamic and condensed matter systems, plasma physics, biological physics, semiconductor principles and devices, quantum electronics, and low-dimensional electronic systems.

Students are encouraged early on to develop strong experimental skills for advanced laboratory work, including familiarity with numerical computation for data and image analysis and software packages for instrument automation. There exist many learning opportunities along these lines, from courses in microfabrication and laboratory work to independent research opportunities with various research groups. Undergraduate students are encouraged to explore and will find numerous opportunities for developing their research interests into junior or senior thesis projects leading to publication.

PHYSICAL FACILITIES

Research in applied physics covers a broad spectrum of activities distributed across campus. Instructional and research activities of the core faculty are housed in the Thomas J. Watson, Sr. Laboratories of Applied Physics, a 40,000-square-foot building with state-of-the-art research laboratories, a central microfabrication facility, faculty and student offices, and a conference room and instructional classroom, all nestled around a beautiful courtyard with a fountain pool.

Additional research laboratories and faculty and student offices are located in the Harry G. Steele Laboratory of Electrical Sciences, built in 1965 with funds from the Harry G. Steele Foundation and the National Science Foundation. The building, which is connected by an overhead bridge to the Watson Laboratories, conveniently also houses the Kavli Nanoscience Institute.

ASTROPHYSICS

Caltech is one of the world's preeminent centers of astronomical research. This is due to the combination of excellent human resources with premier observational facilities and computational infrastructure. Fundamental discoveries in astronomy and astrophysics are a part of Caltech's past, present, and future.

Students from either the astronomy or the physics options are best prepared to undertake research with faculty in the Cahill Center for Astronomy and Astrophysics. Students from related options such as planetary science, computer science, applied physics, and electrical engineering are also welcome.

AREAS OF RESEARCH

Astronomy and astrophysics are synonymous at Caltech. Caltech scientists and students are involved in many frontier areas of research, and have been known to open new ones. Research techniques include observations, theory, numerical simulation, advanced data analysis, laboratory astrophysics, and detector development. Projects and groups often bridge these areas of inquiry.

Topics of current research interest include: observational cosmology and the nature of dark matter and dark energy; studies of the cosmic microwave background; galaxy formation and evolution; quasars and other active galactic nuclei and radio sources; studies of the dynamics and composition of galaxies and clusters; physics and

evolution of the intergalactic medium; interstellar matter; local star and planet formation; extrasolar planetary systems; the structure of the galaxy; globular clusters; stellar abundances; supernovae, gamma-ray bursts, and other types of cosmic explosions and transient phenomena; neutron stars and black holes; accretion disks; digital sky surveys and astroinformatics; numerical general relativity; gravitational wave astronomy and many others.

Research in planetary and solar system astronomy is often pursued in cooperation with groups in the Division of Geological and Planetary Sciences. New types of astronomical detectors and satellites, that can revolutionize various areas of astronomical research, are developed with groups in physics and colleagues at JPL.

In addition to maintaining a leading numerical general relativity group, Caltech theorists also use high-performance computing facilities for simulations of supernova explosions, merging black holes, cosmic structure formation, etc. Caltech is leading the development of novel tools for knowledge discovery in massive and complex astronomical data sets, many obtained with Caltech facilities.

HISTORY AND CURRENT SCIENCE AT OBSERVATIONAL FACILITIES

Observational astronomy is pursued both from the ground-based sites and from space-based platforms. Caltech operates, or has access to an unprecedented, comprehensive set of observational facilities, spanning the entire electromagnetic spectrum. Caltech is also playing a key role in opening a new window on the universe, the gravitational wave sky.

Historically, Caltech's pioneering role in astronomy started with Palomar Observatory (about 190 km from campus), funded by the Rockefeller Foundation. The first telescope on the mountain was an 18-inch Schmidt telescope built by Fritz Zwicky and used to conduct pioneering sky surveys for supernovae, potential planetary hazard asteroids, etc. The 200-inch Hale Telescope, constructed through the 1930s and 1940s, has been used to make many historical, fundamental discoveries ever since its commissioning in 1948, including the discovery of quasars, and many studies of stellar populations, galaxies, intergalactic medium, etc., and it continues to produce excellent science. Novel detectors and instruments were developed there, e.g., the first astronomical CCDs and infrared detectors as well as pioneering advances in adaptive optics in addition to optical and infrared spectroscopy. The 48-inch Samuel Oschin Telescope has made possible complete surveys of the northern sky, initially with photographic plates (including the historic POSS-I and POSS-II surveys), and now with large-format CCD array cameras. It is currently operating a uniquely wide field, high-cadence program, the Zwicky Transient Facility (ZTF). A much larger camera for this telescope, with a 47-square-degree field, started operation in 2018, as the Zwicky Transient Facility (ZTF). The 60-inch telescope has been roboticized, and is used to monitor sources discovered by sky surveys.

In the 1990s, funded mainly by the Keck Foundation, Caltech and University of California constructed two 10-m telescopes on Mauna Kea, Hawaii. The W. M. Keck Observatory produced many recent discoveries in the fields of galaxy formation and evolution, intergalactic medium, extrasolar planets, cosmic gamma-ray bursts, etc. Caltech is a founding partner in the development of the Thirty-Meter Telescope (TMT), the first of the next generation of extremely large optical/infrared telescopes.

At meter to centimeter wavelengths, Caltech operates the Owens Valley Radio Observatory (OVRO) in a radio-quiet location about 400 km from Pasadena, near Big Pine, California. Its facilities include a 40-meter telescope, a growing 288 element long wavelength array which can image the entire sky every second, and a 6.1 meter telescope dedicated to observations of polarized radio emission from the galaxy. New radio and sub-mm telescopes are in design and construction phases. From the 1980s until 2015, Caltech also operated the Caltech 10-m Submillimeter Observatory (CSO) on Mauna Kea in Hawaii, and a series of millimeter interferometers, culminating in the 23-antenna Combined Array for Research in Millimeter-wave Astronomy (CARMA) in the Inyo Mountains. These telescopes, currently being repurposed to new experiments, pioneered submm imaging and interferometry and mm wave interferometry, now carried out by the international Atacama Large Millimeter/submm Array (ALMA).

In Antarctica, Caltech's BICEP2 telescope, which measures the imprint of inflation's gravitational waves on the COSMIC microwave background, has been expanded and renamed the Keck Array.

On the space observations front, Caltech hosts NASA's Spitzer Science Center (SSC) and IPAC, which are principal national archives for astronomy. Caltech scientists lead or actively participate in a number of astrophysics missions, currently including the Spitzer Space Telescope, and the NuSTAR hard X-ray mission. Caltech and the Jet Propulsion Laboratory (JPL) are also leading the development of the forthcoming SPHEREx mission, that will study the early stages of the universe, galaxy formation, and formation of planetary systems. There are numerous close connections with JPL, that designs and operates a number of NASA's scientific missions. Finally, Caltech astronomers are major users of NASA's astronomical satellites, the Hubble Space Telescope, Chandra, Fermi, Herschel, Planck, etc., ALMA and the NSF's Jansky Very Large Array (JVLA).

Caltech is the headquarters for LIGO lab, which built and operates the world's most sensitive gravitational wave observatory, the Advanced Laser Interferometer Gravitational-wave Observatory (LIGO), which in 2015 made the historic first detection of gravitational waves from a black hole binary. Several other black hole mergers have been detected since then, as well as the first gravitational wave detection of a merger of two neutron starts in 2017. Numerous other discoveries are expected as the operations continue.

BIOCHEMISTRY AND MOLECULAR BIOPHYSICS

The Biochemistry and Molecular Biophysics (BMB) option has been established as an interdisciplinary program, at the interface of biology, chemistry, and physics, that seeks to understand the chemistry of life. Thus, BMB students study the atomic structure and folding of biopolymers; their interactions with each other and with small molecules; and the roles of particular biopolymers and biopolymer assemblies in cellular physiology. The basic building block of life is the cell; the intellectual focus of modern biochemistry and molecular biophysics is to understand how individual parts interact to give cells their wide spectrum of functions. In particular, biochemistry and molecular biophysics addresses the principles through which the individual components of cells combine in an orderly self-association to produce their form, their function, and their dynamic behavior.

AREAS OF RESEARCH

General areas of research represented within the option include signal transduction, cell cycle, DNA and RNA structure and metabolism, control of gene transcription during development, protein folding, biogenesis and quality control, electron transport proteins and bioenergetics, biological catalysis, macromolecular structure, membrane proteins, and biotechnology and biomolecular engineering. More specific examples of biological phenomena currently under study include the transduction of signals received by cell surface receptors into an appropriate response, as in chemotaxis or transmission of signals across synapses in the nervous system; the replication of DNA; the biochemical networks that control initiation and termination of cell division; the controlled transcription of DNA sequences in the genome into RNA and the processing of this RNA into mRNA and the subsequent translation into protein; energetic principles and molecular mechanisms that underlie the biogenesis of nascent proteins and maintenance of protein homeostasis in the cell; the molecular mechanisms controlling the differentiation of precursor cells into specialized cells such as neurons, lymphocytes, and muscle cells; the mechanisms by which synaptic transmission in the brain is regulated during thinking and the formation of memories; the processes, driven by fundamental principles of chemical bonding and molecular energetics, by which a given linear sequence of amino acids folds into a specific three-dimensional structure in the appropriate cellular environment; how electrons move within a cell to accomplish the many redox reactions necessary for life; how light is harvested by photo-pigments and is perceived in vision; the function of integral membrane proteins in energy and signal transduction processes; and the mechanisms by which enzymes both efficiently and specifically catalyze biochemical interconversions. This fundamental understanding of the molecular basis of biological processes provides a powerful base for the development of applications in medicine, including biotechnology and rational drug design, and in the chemical

industry, where nucleic acids, proteins, and their analogs are now being used in the development of chemical systems for novel applications, and where mutagenesis and selection systems are used to produce novel materials.

BIOENGINEERING

Bioengineering research at Caltech focuses on the application of engineering principles to the design, analysis, construction, and manipulation of biological systems, and on the discovery and application of new engineering principles inspired by the properties of biological systems.

AREAS OF RESEARCH

- *Bioimaging* (Cai, Dickinson, Gharib, Lester, Meyerowitz, Pierce, Shapiro, Yang)
  Biophotonics, advanced imaging technologies, computational image analysis, noninvasive biomedical imaging, single-molecule technologies, flow-field imaging technologies, in situ amplification.
- *Bioinspired Design* (Gharib, Greer, Hajimiri, Ismagilov, Murray, Shapiro, Tirrell, Winfree)
  Engineering physiological machines, engineering self-powered technologies, control systems, synthetic heteropolymers, and self-healing circuits and systems.
- *Biomechanics* (Bhattacharya, Dickinson, Gharib, Greer, Meyerowitz, Phillips, Roukes)
  Molecular and cellular biophysics, cardiovascular mechanics, muscle and membrane mechanics, physiology and mechanics offlapping flight, multicellular morphodynamics, cell-biomaterial interactions.
- *Biomedical Devices* (Burdick, Emami, Gharib, Hajimiri, Heath, Ismagilov, Meister, Roukes, Shapiro, Siapas, Tai, Yang)
  BioNEMS, BioMEMS, laboratories-on-a-chip including microfluidic systems, neural networks, microscopes and diagnostics, novel measurement principles, neural interfaces and prostheses, locomotion rehabilitation, molecular imaging during surgery.
- *Cell and Tissue Engineering* (Arnold, Elowitz, Gharib, Gradinaru, Ismagilov, Shapiro, Tirrell)
  Multicellular morphodynamics, principles of feedback between tissue mechanics and genetic expression, non-natural protein biomaterials, cell-biomaterial interactions, developmental patterning.
- *Molecular Medicine* (Baltimore, Bjorkman, Davis, Deshaies, Gradinaru, Hay, Ismagilov, Lester, Mazmanian, Pierce)
  Engineering immunity, cancer vaccines, AIDS vaccine, novel anti-cancer therapeutics, Parkinson's disease, schizophrenia, Huntington's disease, nicotine addiction, microbiome perturbations in disease, molecular basis of autism,

programmable chemotherapies, conditional chemotherapies, nanoparticle drug delivery.

- *Molecular Programming* (Aravin, Murray, Pierce, Qian, Rothemund, Winfree)
  Abstractions, languages, algorithms, and compilers for programming nucleic acid function, molecular information processing, molecular complexity theory, free-energy landscapes, metastable systems, self-assembly across length scales, algorithmic self-assembly, synthetic molecular motors, in vitro and in vivo nucleic acid circuits.
- *Synthetic Biology* (Aravin, Arnold, Elowitz, Gradinaru, Ismagilov, Murray, Pierce, Qian, Rothemund, Shapiro, Tirrell, Winfree)
  Principles of biological circuit design, genetic circuits, protein engineering, noncanonical amino acids, nucleic acid engineering, rational design, directed evolution, metabolic engineering, biofuels, biocatalysts, elucidation of systems biology principles using synthetic systems.
- *Systems Biology* (Aravin, Cai, Doyle, Elowitz, Goentoro, Heath, Ismagilov, Lester, Meister, Meyerowitz, Murray, Phillips, Sternberg, Winfree)
  Roles of circuit architecture and stochasticity in cellular decision making, feedback, control, and complexity in biological networks, multicellular morphodynamics, principles of developmental circuitry including signal integration and coordination, spatial patterning and organ formation, principles of feedback between tissue mechanics and genetic expression, neural development, and disease.

BIOLOGY

Recent dramatic progress in our understanding of the nature of life has revolutionized the science of biology. Applications of the methods, concepts, and approaches of modern mathematics, physics, chemistry, and information science are providing deep insight into basic biological problems such as the manner in which genes and viruses replicate themselves; the control of gene expression in cells; the regulation of cellular activity; the mechanisms of growth and development; and the nature and interactions of nerve activity, brain function, and behavior. Qualified experimental and computational biologists will find opportunities for challenging work in basic research as well as in medicine and in biotechnology.

Because of the eminent position of Caltech in both the physical and biological sciences, students at the Institute have an unusual opportunity to be introduced to modern biology.

AREAS OF RESEARCH

Research (and graduate work leading to the Ph.D. degree) is chiefly in the following fields: biochemistry, biophysics, cell biology, developmental biology, genetics, genomics and computational biology, immunology, microbiology, molecular biology, neurobiology, structural biology, and systems biology. Biochemical methodology plays an important role in many of these fields, and there is extensive interaction with related programs in biochemistry within the Division of Chemistry and Chemical Engineering, including the biochemistry and molecular biophysics option.

The programs in cellular, molecular, and developmental biology are based upon approaches derived from biochemistry, biophysics, and genetics that offer new possibilities for expanded insight into long-standing problems. Neurobiology is a major area of emphasis within the Division of Biology and Biological Engineering. A comprehensive program of research and instruction in neurobiology has been formulated to span from molecular and cellular neurobiology to the study of animal and human behavior, including the computational modeling of neural processes.

A geobiology option is described in the geological and planetary sciences section.

PHYSICAL FACILITIES

The campus biological laboratories are housed in seven buildings: the William G. Kerckhoff Laboratories of the Biological Sciences, the Gordon A. Alles Laboratory for Molecular Biology, the Norman W. Church Laboratory for Chemical Biology, the Mabel and Arnold Beckman Laboratories of Behavioral Biology, the Braun Laboratories in Memory of Carl F and Winifred H Braun, the Beckman Institute, and the Broad Center for the Biological Sciences. They contain classrooms and undergraduate laboratories, as well as research laboratories where both undergraduate and graduate students work in collaboration with faculty members. Special facilities include rooms for the culturing of mutant types of *Drosophila,* a monoclonal antibody production facility, a fluorescence-activated cell sorter facility, scanning and transmission electron microscopes, a confocal microscope facility, a magnetic resonance imaging center, a transgenic mouse facility, a high throughput sequencing and microarray analysis facility, and a protein expression and purification center.

About 50 miles from Pasadena, in Corona del Mar, is the William G. Kerckhoff Marine Laboratory. This laboratory provides facilities for research in cellular and molecular biology using marine animals, and for collecting and maintaining these animals.

CHEMICAL ENGINEERING

The chemical engineering faculty teach and conduct research on fundamental chemical, biological, and transport processes and their application in understanding, designing, and controlling a broad spectrum of complex chemical, biochemical, and environmental processes. The faculty and students utilize their analytical skills and laboratory resources to study diverse processes and to synthesize new materials. The combination of engineering principles, chemistry, biology, physics, and mathematics that characterizes chemical engineering at Caltech enables students and faculty to contribute to the solution of a wide range of critical problems and to aid in creating new areas of science and technology.

AREAS OF RESEARCH

Many different research areas are offered to students seeking the degrees of Master of Science or Doctor of Philosophy in chemical engineering. Particular research fields emphasized in the department include the following:

- *Biological Design and Engineering.* Protein engineering by evolution and machine learning. New-to-nature biocatalysis for sustainable production of pharmaceuticals and specialty chemicals. Gene editing and genome engineering of plants.
- *Fluid Mechanics and Transport Processes.* Mechanics of polymeric liquids, microstructured fluids, colloidal dispersions and suspensions, and granular media. Transport in heterogeneous media.
- *Polymer Physics and Chemistry.* Molecular understanding of polymer melts, gels and solutions. Optical and rheological properties of polymers. Dynamic modeling of polymer structure and rheology. Synthesis of tailored polymers by chemical and biological means.
- *Biomaterials.* Synthesis and properties of organic materials designed for use in living systems. Therapeutic modification of existing systems.
- *Cellular Engineering* . Quantitative analysis and redesign of molecular events governing cell behavior. Plant synthetic biology, bioengineering, and biotechnology.
- *Electrocatalysis and Biocatalysis.* Design of catalytic sites engaged in making and breaking chemical bonds while transferring electrons. Development of biotic and abiotic approaches to harnessing renewable energy for chemical transformations, ranging from heterogeneous electrocatalysts to electrified enzymes.
- *Chemical Dynamics and Surfaces:* Kinetic-energy-driven, non-catalytic reactions with applications in plasma processing and astrophysical environments. Eley-Rideal reactions and collision-induced dissociation at surfaces. Water-splitting and carbon dioxide dissociation at oxides.

- *Complex networks of reactions, cell, and organisms in space and time.* Studies of microbial communities in environment and interactions of microbial communities with their human host.
- *Microfluidics.* Science of single molecules and cells. Fundamental studies of fluid flow and interfacial phenomena. Engineering of solutions to diagnostic and therapeutic problems in Global Health, including antibiotic resistance.
- *Nanotechnology.* Aerosol synthesis of nanoparticles for micro-electronic and photovoltaic applications. Electrospraying and electrospinning of nanostructured electrolytic materials for energy conversion and desalination. Novel electrodes for fuel cells, batteries, and super capacitors. Nano-membranes. Nanoparticales for biomolecule delivery to plants.
- *Environmental Chemical Engineering* . Physics and chemistry of atmospheric gases and aerosols, bioaerosols, climate change, bioldegradation of persistent chemicals. Sustainable agriculture through rhizosphere engineering.
- *Aerosols and Colloids.* Nucleation and growth of particles. Particle formation and reactions. Structure and properties of colloidal dispersions. Aerosol and colloidal particle characterization.
- *Applied Mathematics and Computational Physics.* Supercomputer applications in fluid mechanics and environmental modeling. Concurrent computing. Asymptotic analyses of transport processes. Data analysis and machine learning.
- *Physics of Soft and Active Matter* .
- Structures, phase transitions, and dynamics of polymers, liquid crystals, surfactant solutions, gels, colloidal dispersions and active matter.
- *Nanoscale Thermodynamics and Dynamics.* Flow and crystalization of materials in nanoscale confinement. Wall effects, lattice melting, capillary condensation. Structure, transport and charging/discharging in confined electrolytes.

PHYSICAL FACILITIES

The chemical engineering laboratories, mainly housed in the Eudora Hull Spalding Laboratory of Engineering and the Warren and Katharine Schlinger Laboratory for Chemistry and Chemical Engineering, are well equipped. The facilities include experimental reactors, computational facilities, NMR spectrometers, and numerous special research equipment for molecular simulations, DNA synthesis, and electronic, optical, and chemical measurements.

CHEMISTRY

Caltech offers exciting opportunities for study and research at the frontiers of chemical science. With approximately 30 faculty, the chemistry program provides depth in the traditional areas of chemistry—organic and inorganic chemistry, chemical physics, theoretical chemistry, and chemical biology. Research areas include chemical synthesis and catalysis, chemical dynamics and reaction mechanisms, biochemistry, bioinorganic, bioorganic, and biophysical chemistry, and materials chemistry. Chemical research at Caltech is also highly interdisciplinary, mirroring the increasing importance of molecular understanding in many fields of science. Active interactions exist between chemistry and other disciplines at Caltech, especially applied physics, biology, chemical engineering, environmental science, geological and planetary sciences, and materials science. Major initiatives are fostering broad collaborations in energy and environment, molecular medicine, and nanomaterials.

Teaching is an important component of the chemistry option. Caltech has trained generations of chemists who have become leaders in academia, industry, and government, through undergraduate and graduate programs that are designed to encourage the greatest possible amount of freedom, creativity, and flexibility.

AREAS OF RESEARCH

Caltech has a long and continuing reputation for excellence in fundamental chemistry in molecular structure and the nature of chemical bonding. Much of the current research in chemistry is directed at establishing and manipulating the mechanisms of reactions of fundamental chemical and biological significance. Programs in chemical physics emphasize studies of molecular dynamics and structure using techniques that include femtosecond lasers, molecular beams, ultra-high sensitivity spectroscopy, and mass spectrometry, while novel methods such as ultrafast electron diffraction and force-detected magnetic resonance are being developed and applied to systems of increasing complexity. Interdisciplinary research includes the development of powerful approaches to fabricate, assemble, and utilize nanometer-scale structures; spectroscopy and fundamental chemical mechanisms of reactions in Earth and planetary atmospheres, star formation, and interstellar chemistry; the dynamics of phase transitions; and novel methods in mass spectrometry.

Catalysis by transition metals represents a central area of research in the inorganic and organometallic areas. Current research interests include the uses of transition metal complexes as homogeneous and heterogeneous catalysts for polymer synthesis, solar energy conversion and storage, and methane and water oxidation. Reactions of molecules on surfaces are an important focus, especially on semiconductors. Research in bioorganic and bioinorganic chemistry includes the chemical basis of synaptic transmission by ion channels; investigations of molecular recognition and sequence-specific ligand binding to DNA; DNA-mediated charge transport; and design of

artificial transcription activators.

Chemical synthesis, a key part of much of the research described above, is the primary research goal of several groups, and includes projects aimed at the synthesis of complex organic molecules of importance in biology and human medicine. These efforts include development of new and synthetically useful chemical transformations mediated by novel organic and transition metal-based catalysts. The division has an exceptional program in polymer science, with emphasis on the development of strategies and methodologies for the synthesis of designed polymers using chemical- and biological-based approaches.

The theoretical chemistry program ranges from fundamental studies of electron transfer to excited states and reaction dynamics of small molecules, to simulations of biological systems and materials. In these studies, theoretical techniques are being developed to provide detailed understanding of electron transfer processes, proton transfer reactions, energy randomization processes within molecules, and the dynamics of reacting systems. Computer simulations are addressing ever more complex systems, ranging from metals and superconductors to soft materials and biomolecules.

Research in biochemistry and molecular biology within the chemistry division exists within the larger framework of biochemical studies at Caltech, and includes crystallographic and spectroscopic analyses of macromolecule structures; studies on the design, folding, and stability of macromolecules; the mechanisms of enzyme catalysis and allosteric transitions; interactions between proteins and nucleic acids; macromolecular assemblies mediating replication, transcription, and protein biosynthesis; the mechanism and functional role of protein glycosylation; and mechanisms of ion and electron transport in biological membranes.

PHYSICAL FACILITIES

The laboratories of chemistry consist of eight units providing space for about 25 research groups, including 300 graduate students and postdoctoral research fellows. Crellin and Gates laboratories house several research groups, the divisional instrumentation facilities, and the divisional administrative offices. Synthetic research groups occupy the Arnold and Mabel Beckman Laboratory of Chemical Synthesis and Church laboratories. The Braun Laboratories and the Broad Center for the Biological Sciences house biochemical groups and are shared with the Division of Biology and Biological Engineering. The Arthur Amos Noyes Laboratory of Chemical Physics is one of the major research facilities for chemical physics and inorganic chemistry and is adjoined by the Clifford S. and Ruth A. Mead Memorial Undergraduate Chemistry Laboratory. Chemistry groups recently joined several chemical engineering colleagues in the new Warren and Katharine Schlinger Laboratory for Chemistry and Chemical Engineering. A number of resource centers serving researchers of the division are located in the Beckman Institute.

CIVIL ENGINEERING

Civil engineering includes the research, development, planning, design, and construction associated with the infrastructure of the built environment. Dealing with the function and safety of such facilities as buildings, bridges, pipelines, dams, power plants, and harbors, it is concerned with the protection of the public against natural hazards such as earthquakes, winds, floods, landslides, water waves, and fires.

Recent advances in technology, the escalation of urban problems, and the exploration of space have broadened the applications of civil engineering, increasing the scope of research. New problems have presented special challenges to the civil engineer well-trained in the fundamentals of their profession. For this reason, in the advanced study of civil engineering at the Institute, the application of fundamental scientific principles and mathematics is emphasized for the solution of engineering problems.

AREAS OF RESEARCH

Graduate work leading to advanced degrees lies chiefly in the following fields: structural engineering and structural dynamics; earthquake engineering; applied mechanics; geotechnical engineering; aerospace structures; and environmental engineering (see also environmental science and engineering). In the past few years, graduate students and members of the faculty have pursued a variety of research programs, including the analysis of structures subjected to earthquakes and other dynamic loadings; optimal performance-based structural design; system identification and control of structures; structural health monitoring; the use of finite element methods for structural analysis; seismic risk and structural reliability; earthquake early warning systems; mechanics of soil and other granular materials; and mechanics of space structures. Students whose interests are in environmental problems may enroll for graduate degrees in either civil engineering or environmental science and engineering.

PHYSICAL FACILITIES

Civil engineering activities are housed in the Gates-Thomas Laboratory. Excellent computing facilities are available through the campus computing network and in the specialized computing centers of various research groups. Seismic instrumentation networks include the Southern California Seismic Network and the Community Seismic Network.

COMPUTATION AND NEURAL SYSTEMS

What does the brain compute? How does it do it? And why? Faculty and students in the CNS option study how information is acquired and processed by the brain. They are also interested in designing machines that are adaptable, intelligent, and autonomous. The unifying theme of the program is the study of the relationship between

the physical structure of a computational system (synthetic or natural hardware), the dynamics of its operation and its interaction with the environment, and the computations that it carries out.

Areas of interest include coding and computation in networks of neurons, sensory systems (vision, audition, olfaction), learning and memory, control and motor behavior, and planning and decision making. Thus, CNS is an interdisciplinary option that benefits from, and integrates, multiple traditional areas of expertise: molecular, cellular, neural, and systems biology, electrical and mechanical engineering, computer science, psychology, and cognition, applied mathematics, and physics.

Faculty in the program belong to the Division of Biology and Biological Engineering, Division of Engineering and Applied Science, Division of Physics, Mathematics and Astronomy, and Division of the Humanities and Social Sciences. They have an interest in developing conceptual frameworks and analytical approaches for tackling seemingly disparate problems that share a common deep structure at the computational level. Students in the program will partake of a wide-ranging curriculum that will promote a broad understanding of neurobiology, sensory psychology, cognitive science, computational hardware and software, and information theory.

AREAS OF RESEARCH

Areas of research include the neuron as a computational device; the theory of collective neural circuits for biological and machine computations; algorithms and architectures that enable efficient fault-tolerant parallel and distributed computing; learning theory and systems, pattern recognition, information theory, and computational complexity; computational modeling and analysis of information processing in biochemical and neural networks; the design and use of synthetic macromolecules as computational devices; light and magnetic resonance imaging of cell lineages, cell migrations, and axonal connections in the forming nervous system; learning, plasticity, and memory; experimental and modeling studies of localization and recognition by sensory systems (vision, olfaction, audition) in insects and vertebrates on the basis of electrophysiology, psychophysics, and functional imaging techniques; multiunit recordings in behaving animals; neuroprosthetic devices and recording methods in animals and humans; imaging and stimulation of cortical areas in humans and other primates using functional MRI, TMS, and tDCS; decision making, attention, awareness, emotion, and consciousness in the primate brain using a combination of neurophysiological, psychophysical, and computer modeling techniques; cognitive psychology; and the study of evolution in natural and artificial systems.

COMPUTER SCIENCE

Computing is a ubiquitous tool in all areas of study and research at Caltech. Computer science focuses on the theory and technology of computation itself: it is the study of information, and of the structures that communicate, store, and procegs information. Whether these structures are expressed in hardware and called machines, in software and called programs, or in nature or society, the fundamental concepts are similar.

Students of the computer science option within the Computing & Mathematical Sciences department at Caltech do not specialize along traditional lines that divide hardware and software, systems and applications, or theory and experiment. Rather, a unified approach to the design and analysis of computing structures is taken both in courses and in research. Managing the great complexity of useful systems requires a representation of computations amenable to both mathematical treatment and implementation. Whether the system is artificially designed (such as a multi-core processor), or naturally occurring (such as a molecule), the computer scientist formalizes the computation performed by the system and provides a systematic analysis of its requirements and formal guarantees on its outcomes.

AREAS OF RESEARCH

Research and advanced courses leading to the Ph.D. degree in computer science are concentrated in the following areas: quantum and molecular computation; parallel and distributed computation; theory of computation; information theory; machine learning and applications; computational economics; computer vision; computer graphics; discrete differential geometry; networking and power systems. Research projects frequently involve work in several of these areas, with both theoretical and experimental aspects, as well as connections with such fields as mathematics, physics, biology, economics, and electrical engineering. Crosscutting themes include:

- *Physical Implementation of Computations.* Computations must ultimately be implemented in some physical medium (e.g., semiconductor electronics, DNA self-assembly, quantum states of elementary particles, molecular electronics). Caltech has been a leader in the early development, engineering, and design of very large scale integrated (VLSI) circuits. Beyond VLSI, efforts are under way to understand quantum, biomolecular, and molecular electronic substrates as possible media for future computing machines. As was the case with semiconductor electronics, Caltech computing can draw on the world-class expertise of its biology, physics, and chemistry departments as it tackles the many challenging opportunities that these new substrates present.
- *Robust Modeling of Physical Systems.* Caltech computer science has a unique focus in developing rigorous and robust models of the physical world. These models are mathematically and physically sound, often derived from differential geometric

principles, and serve as a basis for computer graphics and vision research, as well as the simulation of mechanical, optical, and biological systems.

- *Systematic Design.* A key theme in the Caltech computer science option is the systematic design of systems at all levels. This theme shows up in the design of numerical algorithms for physical simulation and computer graphics, design of concurrent and distributed systems, abstractions for physical computing substrates, design of learning systems, design of programming languages, automated optimization of computations for both software and hardware implementation, as well as control and optimization of networks. The success of computer systems has allowed the building of systems of unprecedented scale and complexity. These systems can only be understood and managed if we carefully contain the complexity involved by systematically defining and exploring their design space.
- *Theory.* A strong theoretical understanding is the necessary foundation for systematic design, analysis, and verification. The theory of computation focuses on deep mathematical problems, many of which have substantial technological impact. Theory in computer science at Caltech includes traditional areas such as complexity algorithms, theories of numerical computation, optimization, probability, and game theory. But theory is not relegated to a single group, and has strong connections to all disciplines represented at Caltech.
- *Networks & Distributed Systems.* Modern networks and distributed systems are undoubtedly the most complex and critical pieces of infrastructure that the world has created. This includes communication networks as well as power networks, social networks, cloud computing, and more. The massive scale and exponential growth of such networks presents unique algorithmic, computational, and economic challenges. Research at Caltech approaches these challenges through a combination of rigorous design, systematic analysis, and interdisciplinary collaboration.
- *Machine Learning.* In our increasingly data-rich world, it is more important than ever to develop principled approaches that can intelligently convert raw data into actionable knowledge. At Caltech, we take a broad and integrated view of research in data-driven intelligent systems. The Decision, Optimization and Learning group brings together researchers from machine learning, optimization, applied math, statistics, control, robotics, distributed systems and human-computer interaction to form an intellectual core pertaining fundamental and applied research from statistical machine learning to statistical decision theory through optimization.
- *Interdisciplinary Research.* Computer simulations, modeling, and analysis are key enablers, allowing all fields of science to advance rapidly. Furthermore, insights into computational management of information helps us understand information processing issues in natural systems (from cells and neurons to

financial markets and social networks) and build hypothetical models that advance our understanding of natural cognition. These relations provide many opportunities for scholars in computer science to work closely with colleagues throughout Caltech. The Information Science and Technology (IST) initiative facilitates and promotes such interdisciplinary research (see ist.caltech.edu).

COMPUTING AND MATHEMATICAL SCIENCES

Data-driven modeling is becoming increasingly critical in diverse application domains such as machine learning, vision, control systems, biological and engineered networks, neuroscience, economics, and privacy, as well as in many areas of the physical sciences, including high energy physics, earthquake modeling, astronomy, and exploration geophysics. There is enormous potential for research on data-intensive activity of this type, which is highlighted by the emergence of new fields such as "Big Data," "Decision Science," and "Network Science." However, the theoretical foundations of these subjects remain underdeveloped, limiting our understanding and development.

The mission of the CMS graduate program is to address this need by exploring and developing the fundamental mathematical, computational, and economic tools necessary to advance data-intensive science and engineering. That is, we aim to forge the algorithmic foundations necessary to move from data, to information, to action. Key to this mission is a core focus on "algorithmic thinking." Algorithms are not just the basis for advanced technology, they are intrinsic components of diverse fields such as biology, physics, and economics. Studying the structures and mechanisms that communicate, store, and process information from this viewpoint—whether these structures are expressed in hardware and called machines, in software and called programs, in abstract notation and called mathematics, or in nature and society and called biological or social networks and markets—is crucial to pushing scientific boundaries. Simply put, it is almost impossible to do research in any scientific or engineering discipline without the ability to think algorithmically.

Because of the diversity of fields where algorithmic thinking is fundamental, there are broad differences in how algorithms are formalized, applied, and studied across areas. Over the years, these differences have been codified and the "language of algorithms" is actually quite distinct across, e.g., computer science, applied math, and electrical engineering. However, a broad view of algorithmic thinking is crucial to scientific breakthrough; and the goal of this program is to train scholars to have an interdisciplinary, cross-cutting view of algorithms.

Faculty and students in CMS are active in a broad array of research areas. Some of these include algorithms, complexity, algorithmic economics, feedback and control, inference and statistics, information systems, machine learning, networked systems, vision, optimization, quantum information, scientific computing, and uncertainty quantification.

CONTROL AND DYNAMICAL SYSTEMS

Some of the most exciting interactions between mathematics and engineering are occurring in the area of analysis and control of uncertain, multivariable, and nonlinear dynamical systems. While changing technology has made control and dynamical systems theory increasingly relevant to a much broader class of problems, the interdisciplinary nature of this area means that it no longer has a natural home exclusively or even primarily within any one of the traditional engineering disciplines. The CDS option, as part of the Computing & Mathematical Sciences department, is designed to meet the challenge of educating students both in the mathematical methods of control and dynamical systems theory and their applications to problems in engineering and science.

Faculty and students in CDS are active in a number of research areas. The primary theoretical areas of research include stochastic and nonlinear dynamical systems, multiscale modeling, optimal and decentralized control, system identification and estimation theory, Bayesian modeling and analysis, uncertainty quantification, and communications and information theory. Active applications include networking and communication systems, embedded systems and formal verification, robotics and autonomy, molecular and systems biology, integrative biology, human physiology, economic and financial systems, computing systems, physics of fluids, quantum mechanics, seismology and earthquake engineering, and space systems.

ELECTRICAL ENGINEERING

Electrical engineering at Caltech emphasizes both devices and systems. Closely allied with computation and neural systems, applied physics, bioengineering, computer science, and control and dynamical systems, it offers students the opportunity for study and research, both theoretical and experimental, in a wide variety of subjects, including wireless systems, photonics, quantum information science, modern optics, biophotonics, MEMS/NEMS, solid-state materials and devices, power electronics, energy systems, control theory, data science, nanoscale systems, signal processing, learning, data compression, and communications.

AREAS OF RESEARCH AND PHYSICAL FACILITIES

Substantial experimental laboratory facilities, housed mainly in the Moore Laboratory of Engineering, are associated with each of the research fields described on the following pages.

- Artificial Intelligence, Machine Learning, Neural Networks, and Neuronal Networks (Yaser Abu-Mostafa, Katie Bouman, Jehoshua [Shuki] Bruck, Michelle Effros, Georgia Gkioxari, Pietro Perona) Theoretical and applied research in machine learning, artificial intelligence, and neural networks. Theoretical efforts focus on estimating the amount of information (data and prior knowledge) required to learn a given task, understanding the computational complexity of neural networks, and modeling how biological neural networks give rise to brain function. Applied research spans a range of domains including medicine, biology, computer vision, natural language processing, robotics, computational imaging, e-commerce, and computational finance. Ongoing projects include AI-based diagnostics using low-resolution ultrasound and detection of blood micro-clots (Abu-Mostafa), new methods for incorporating prior knowledge into learning (Abu-Mostafa), a data-driven model for predicting the spread of COVID-19 in U.S. counties (Abu-Mostafa), visual categorization (Perona), algorithms learning from crowds of experts (Perona), modeling and analysis of animal and human behavior (Perona), developing novel computational models that can reason in three dimensions from two-dimensional visual inputs, enabling robotic agents to effectively interact with their environment through perception (Gkioxari) and physics-informed AI methods for computational imaging, including the joint optimization of sensor and algorithm design to enable new imaging strategies (Bouman). Other areas include the development of mathematical theory to explain basic brain function including how neuronal networks create, store, and retrieve memories (Effros) and when, how, and how well neuronal networks are able to self-heal after injury (Effros).
- *Bio-Electronics, Bio-Optics, and Medical Imaging* (Azita Emami, Ali Hajimiri, Alireza Marandi, Axel Scherer, Yu-Chong Tai, Lihong Wang, Changhuei Yang)
  Electrical engineering has broadly impacted biomedicine. Integrated circuits are used to detect biological matters, such as DNA and proteins, in various (e.g., electrical, magnetic, optical) sensing modes with high sensitivity. Applications include microarrays and point-of-care. MEMS and nanotechnologies are developed for a new generation of micro-implants. Examples include retinal implants, drug delivery pumps, and bio-analyte sensors. Optical technologies are developed for medical imaging. Current areas of interest include optofluidics, wavefront shaping, wide field-of-view imaging, chip-scale microscopy, Fourier ptychographic microscopy, photoacoustic tomography, microwave-induced thermoacoustic tomography, and light-speed

compressed ultrafast tomography.

- *Biological Information Science* (Michelle Effros)
  Electrical engineering provides tools useful for studying information transmission, storage, and understanding. While the application of these tools is wide spread and well known in technological systems, their application to biological systems is less common but similarly powerful. Current areas of interest include the mathematical theory of information transmission, storage, and understanding in the brain and the investigation of information transmission in DNA.
- *Circuits and VLSI (* Azita Emami, Ali Hajimiri)
  Analysis, design, simulation, verification, and testing of integrated circuits for various applications, such as high-speed and wireless communications, wireless local-area networks, highly stable frequency sources, distributed integrated circuit design techniques for ultrahigh speed silicon-based circuits, system and circuit design for multi- band systems, single-chip spectrum analyzers, performance limitation of A/D and D/A data converters, and robust circuit- design techniques. Projects also include millimeter-wave silicon-based circuits and arrays, flexible and lightweight arrays, wireless power transfer at distance, silicon-photonics and electronics integration, self-healing circuits, high frequency power generation in CMOS, analysis and design of distributed circuits, multimode reconfigurable systems, as well as modeling of the effect of substrate and supply noise in large integrated circuits and design techniques to minimize their effect, examination of integrated passive structures and their fundamental performance limits, and noise modeling in amplifiers, mixers, and oscillators. More information can be found atchic.caltech.edu and mics.caltech.edu.
- *Control and Learning* (Venkat Chandrasekaran, John Doyle, Babak Hassibi, Victoria Kostina, Steven Low, Joel Burdick, Mechanical & Civil Engineering, Richard Murray, Control & Dynamical Systems)
  Theoretical research is conducted in all aspects of control, with emphasis on robustness, multivariable and nonlinear systems, optimal control, networked control with information constraints, learning for dynamical systems, online learning and control, control-theoretic perspectives on deep learning, and reinforcement learning Theoretical developments are applied to a wide variety of areas, including internet, autonomous systems, wireless, power systems, cell biology, autonomy, neuroscience, medical physiology, turbulence, wildfire ecology, earthquakes, economics and finance, and foundations of physics.
- *Devices* (Azita Emami, Ali Hajimiri, Alireza Marandi, Axel Scherer, Yu-Chong Tai, Lihong Wang, Changhuei Yang, Amnon Yariv)
  Research on devices in the Electrical Engineering department deals with a variety of fundamental topics including semiconductor physics, quantum mechanics, electromagnetics, and optics for developing hardware technologies for applications including sensing, communication, computing, and imaging.

These devices can range in size from kilometer scale (such as antenna arrays for radio astronomy), to nano scale (such as building blocks of electronic and photonic integrated circuits).

- *Electromagnetics, RF, Microwave Circuits, and Antennas* (Azita Emami, Andrei Faraon, Ali Hajimiri, Alireza Marandi, Mohammad Mirhosseini, Sander Weinreb)
  Electromagnetics spans most aspects of electrical engineering (and everyday life) from RF, microwave, and mm-wave to infrared and visible optical systems that form the underlying platforms for many of modern marvels. Research involves theoretical study, design, and implementation of devices and systems, such as resonators, radiators, and arrays in microwave and mm-waves, as well as silicon photonics integrated circuits in conjunction with active high speed electronics and photonics integrated circuits. Some examples of such systems include optical phased arrays (OPA) transmitters and receivers, lightweight flexible deployable active phased arrays for communications and power transferm, multimodality quantum computing qubits, and radio astronomy receivers and arrays. This area includes strong theoretical investigations as well as extensive experimental work in realization of these systems in practice.
- *Energy and Sustainability* (John Doyle, Ali Hajimiri, Babak Hassibi, Steven Low, Guillaume Blanquart (Mechanical & Civil Engineering), Adam Wierman (Computing & Mathematical Sciences)
  Energy research at Caltech encompasses control, optimization, and economics of energy systems, especially future smart grid. The goal is to develop a thorough understanding of the world's largest and most complex cyber-physical network as well as an intellectual basis for its transformation into a more sustainable, dynamic, and open system. Current research spans optimal power flow problems, convex relaxations, electric vehicle charging, wireless power transfer, space solar power, energy storage, power system dynamics and control, electricity markets, nonconvex pricing, market power, and cascading failure.
- *Information and Data Science* (Katie Bouman, Venkat Chandrasekaran, Michelle Effros, Babak Hassibi, Victoria Kostina)
  The information and data sciences are concerned with the acquisition, storage, communication, processing, and analysis of data. These intellectual activities have a long history at Caltech both in electrical engineering as well as in allied areas such as applied mathematics. Current research centers around activity at the interface of statistical inference, inverse problems, and machine learning, and has significant synergies with ongoing efforts in information theory and signal processing.
- *Information Theory* (Yaser Abu-Mostafa, Jehoshua (Shuki) Bruck, Michelle Effros, Babak Hassibi, Victoria Kostina, P.P. Vaidyanathan)
  Theoretical work in a wide range of problems involving transmission, storage and manipulation of information, with strong links to optimization, statistics, control, learning, and

wireless communications. Current research foci include bitrate/energy efficiency of computing systems, coding for control, computing with stochastic circuits, error correcting codes for digital storage, coding for delay-sensitive systems, feedback communications, multi-user information theory, parameter estimation with unconventional sampling strategies, random access communications, and random asynchronous computations.

- *MEMS and Micromachining* (Alireza Marandi, Mohammad Mirhosseini, Axel Scherer, Yu-Chong Tai)
  We exercise MEMS, Micro- and nanotechnologies to build various sensor and actuator devices. Current research projects focus on bioMEMS and microimplant applications, including integrated biochips, microfluidic chips, neuron chips, blood-count chips, neuroprobes, retinal implants and spinal cord implants, wireless ECG, etc. Hands-on fabrication of these devices is specially emphasized for every student in the laboratory at Caltech.
- *Networks and Wireless Communication* (Michelle Effros; Babak Hassibi; Victoria Kostina; Adam Wierman, Computing & Mathematical Sciences)
  Research in networks and wireless communication at Caltech spans the spectrum from characterizing theoretical limits of communication system performance to developing algorithms to approximate those limits in practice. Current areas of interest include models and performance analysis for wireless networks, code design and capacity characterization for communication environments characterized by unknown or time-varying channel characteristics, novel modulation schemes, random access communications, remote control over wireless channels, and cloud and edge computing and resource allocation for energy-efficient computing.
- *Optimization* (Venkat Chandrasekaran, John Doyle, Andrei Faraon, Babak Hassibi, Steven Low)
  Optimization is the science of choosing the best element from a collection subject to some constraints.Current research at Caltech spans the spectrum from theoretical foundations to algorithmic development and eventual deployment in applications. In the context of electrical engineering, optimization methods play a prominent role in signal processing, communications systems design, statistical modeling, control, and machine learning.
- *Quantum Science and Engineering* (Andrei Faraon, Alireza Marandi, Mohammad Mirhosseini, Lihong Wang)
  Experimental and theoretical research on physical implementations of quantum information processing systems and on quantum imaging and physics. Current areas of research include: quantum computing hardware (memory, logic, interconnects) based on integrated superconducting circuits, photonics, and acoustics components; architectures for scaling quantum networks and modular quantum computing based on

quantum transducers; understanding the sources of quantum decoherence in solid-state qubits; quantum imaging and physics. See gse.caltech.edu or http://coilab.caltech.edu/ for further details.

- *Signal Processing* (Katie Bouman, Venkat Chandrasekaran, Michelle Effros, Georgia Gkioxari, Babak Hassibi, Pietro Perona, P.P. Vaidyanathan)
  Theoretical and computer-oriented work on a wide variety of problems in digital signal processing, with strong links to optimization, statistics, inverse problems and other areas of applied mathematics. Research areas include sparse sensor arrays, sparse signal reconstruction, compressive sensing, phase retrieval, structured signal recovery, high dimensional statistics, array signal processing, multirate digital filters and filter banks, radar signal processing, genomic signal processing, spectrum sensing, graph signal processing, asynchronous random access communication systems, and lossless source coding and channel coding. Other topics include novel machine learning algorithms with applications in computer vision, visual recognition and categorization, and computational imaging with systems that tightly integrate algorithm and sensor design to find hidden signals for scientific discovery and technological innovation.
- *Vision* (Katie Bouman, Michelle Effros, Georgia Gkioxari, Pietro Perona, Richard Andersen, Computation & Neural Systems, John Allman, Computation & Neural Systems)
  Theory and applications of computer vision. Psychophysics and modeling of the human visual system. Modeling of vision-based decision-making in humans and animals. Current emphasis is on visual object recognition; vision-based human-machine interfaces; perception and modeling of human and animal behavior. Areas of collaboration include statistical machine learning, artificial intelligence, neural networks, computer graphics, neurophysiology, psychology, applied probability, robotics, geometry, and signal processing.

ENERGY SCIENCE AND TECHNOLOGY

The useful transformation of energy from one form to another drives the engine of civilization. Access to plentiful, inexpensive, and environmentally benign resources would free nations to pursue their greatest human and economic potential. In the modern era, the appetite for energy is convoluted, with a recognition of diminishing fossil fuel resources and of dramatic negative impacts on global climate. The interdisciplinary program in Energy Science and Technology (EST) aims to foster revolutionary methods of harnessing carbon-free energy sources while advancing related technologies in carbon sequestration and further drawing connections to policy and economic considerations. The program brings together traditional topics in thermodynamics and kinetics with modern topics in biomolecular engineering, charge and mass transport, and

photoelectrochemistry. Faculty and students in the EST program are drawn from a broad range of academic options, including materials science, chemistry, applied physics, chemical engineering, mechanical engineering, and environmental science and engineering. Areas of emphasis reflect this breadth of disciplines and include photovoltaics, photoelectrochemical cells, bio-fuels, fuel cells, batteries, thermoelectrics, hydrogen generation and storage, and nuclear energy.

ENVIRONMENTAL SCIENCE AND ENGINEERING

Research and teaching in the ESE program span the large scales of global climate variations, the local scales of urban air pollution, and the microscales of microbial ecosystems. Reflecting the interdisciplinary nature of the ESE program, it unites scientists and engineers from Caltech's Division of Geological and Planetary Sciences, Division of Engineering and Applied Science, and Division of Chemistry and Chemical Engineering. Jointly they address, for example, how climate has varied in the past and how it may change in the future, how biogeochemical cycles and chemical reactions control the composition of the atmosphere and local air quality as well as the Earth's global energy balance, and how more efficient and effective ways of producing biofuels or remediating toxic waste can be found. The methods employed in research projects include laboratory studies of fundamental chemical and biological processes; field studies of microbial ecology and of atmospheric chemistry; and computational and theoretical studies of chemical and physical processes on molecular to global scales.

Students enter the ESE program with diverse backgrounds, from the basic sciences of physics, chemistry, and biology to applied science and engineering fields. The curriculum emphasizes interdisciplinary knowledge and is broad, yet it is flexible so that different backgrounds and focus areas can be accommodated.

AREAS OF RESEARCH

- *Atmospheric Chemistry and Air Pollution.* Atmospheric chemistry affects the composition of the atmosphere, properties of clouds, and local air quality. Research areas include cloud chemistry, aerosol chemistry and physics, trace gas photochemistry, and emission sources and transport and reaction pathways of organic species. The methods employed include laboratory studies of aerosol formation and of chemical reactions in the atmosphere; field campaigns with aircraft operated by ESE faculty; satellite missions carried out in collaboration with the Jet Propulsion Laboratory; and theoretical and modeling studies of tropospheric chemistry and the carbon cycle.
- *Environmental Chemistry and Technology.* Environmental chemistry and technology research in ESE addresses

fundamental questions in heterogeneous atmospheric chemistry (e.g., chemistry of clouds, fogs, and haze aerosols), in aquatic chemistry, in oxidation and reduction chemistry and technology, in semiconductor photocatalysis, and in hydrogen production from sunlight via electrochemical water splitting.

- *Dynamics of Climate.* Climate dynamics research in ESE addresses fundamental questions about how Earth's climatic features are maintained, how they have varied in the past, and how they may change in the future. Research includes the large-scale dynamics of the atmosphere and oceans, the hydrologic cycle and how it responds to climate changes, monsoon dynamics, and the dynamics of the Southern Ocean, and climates of other planets. Methods employed include theoretical and modeling studies, analyses of observational data, and field campaigns to collect oceanographic data.
- *Biogeochemistry and Climates of the Past.* Biogeochemical research in ESE finds application at scales ranging from microbial ecosystems to the global carbon cycle. Current research interests include the marine carbon cycle and its geochemical record in organic matter and carbonate minerals; microbial recycling of nutrients and carbon; and development and use of geochemical proxies for understanding the ancient environment, including its climate.
- *Environmental Microbiology.* Microorganisms are the primary drivers of global biogeochemical cycles and represent the most abundant and diverse forms of life on Earth. They catalyze critical biological transformation processes such as nitrogen fixation, oceanic primary productivity, and methane cycling. Microbial ecosystem research within ESE is focused on understanding microbial processes in terrestrial, marine, and extreme ecosystems. Research areas span a range of topics and field sites, including the study of lignocellulose degradation by termite gut microbiota, anaerobic cycling of carbon, nitrogen, and sulfur in microbial mats and sediments, and methane cycling in the ocean.

PHYSICAL FACILITIES

ESE laboratories and facilities are housed in the Ronald and Maxine Linde Laboratory for Global Environmental Science and in other nearby buildings of Caltech's Division of Geological and Planetary Sciences. The laboratories are equipped with a wide variety of state-of-the-art instruments.

- *The Environmental Analysis Center (EAC)* houses analytical instrumentation, for research that ranges from analyzing pollutants in groundwater to dating fossils. Its equipment includes instruments for electrochemistry, plasma emission mass spectrophotometry, gas chromatography, high-performance liquid chromatography, fluorescence spectroscopy, infrared spectrometry, gas chromatography–mass spectrometry, total organic carbon analysis, and electrophoresis and electrical

particle size analysis. Scientists from across the Institute use the EAC for cutting-edge analytical studies.

- *The Atmospheric Chemistry and Aerosol Laboratory* is designed for studies of the photochemical reactions of gaseous and particulate pollutants. In two reaction chambers (28 m^3 each)—the first of their kind when they were built—the chemical reactions that produce urban smog and atmospheric particles are investigated under precisely controllable conditions. They have revealed how the particles that make up smog form in the atmosphere. Research results obtained with them have been instrumental in designing effective air quality policies. They continue to be invaluable in studies of air pollution.

- *The High-Precision Spectroscopy Laboratory* is housed in a quiet room—a room with specially designed acoustic and electromagnetic insulation. Acoustic foam blocks sound waves and copper cladding around the entire room blocks electromagnetic waves. The noise-free environment allows us to achieve exquisite precision in laser measurements of radiative properties of greenhouse gases, aerosols, and atmospheric trace constituents: the properties of single molecules can be measured. The measurements are the basis for climate models and for planning satellite missions to measure the composition of the atmosphere from space.
- *In the Laboratory for Atmospheric Chemical Physics,* the interactions of light with molecules in the atmosphere are investigated to elucidate how pollution forms and to measure the atmospheric concentration of aerosols and greenhouse gases. Techniques are developed for the global monitoring of the atmosphere from mobile ground-based laboratories and from space-based instruments.
- *In the Environmental Chemistry and Technology Laboratory,* collimated sunlight from the Linde + Robinson solar telescope is focused into photolysis reactors, where artificial photosynthesis processes are developed to convert water and carbon dioxide into energetic fuels. Additionally, the chemical nature of the air-water interface is studied, and new technologies are developed for storing electric energy in novel lithium-air batteries and for treating water, for example, by photovoltaically powered electrolysis or ultrasonically induced cavitation.
- *The Geochemistry Clean Room* is designed for trace metal analysis in an entirely metal-free environment. It has air cleansed of almost all particles, to be able to measure with high precision tiny traces of metals and radioactive isotopes found in ocean water and embedded in corals and in stalagmites. These measurements reveal information about how climate has varied in Earth's past and how carbon cycles between the biosphere, the atmosphere, and the oceans. The Clean Room is supported by a plasma mass spectrometry instrument room that contains two multi-collector instruments and a quadrapole instrument. The facility also contains a wet chemistry laboratory for the processing and analysis of environmental samples.

- *The Biogeochemistry Laboratories* provide capabilities for analyzing the structure, abundance, and isotopic composition of organic materials in environmental samples, ranging from organisms to sediments to rocks. Instrumentation includes gas chromatograph–mass spectrometers, isotope-ratio mass spectrometers with capabilities for bulk and compound-specific analysis, a spectroscopic water isotope analyzer, and a combustion elemental analyzer.
- *In the Environmental Microbiology Laboratories* , the diversity and metabolic activities of microorganisms from terrestrial and marine ecosystems are characterized through cultivation, microscopic imaging, metagenomics, and molecular and isotopic analysis. Instrumentation includes anaerobic chambers, platforms for performing microfluidics-based analyses of the nucleic acid contents of environmental single cells, capillary sequencers, quantitative PCR, epifluorescence microscopes, and CAMECA secondary ion mass spectrometers (7f Geo and nanoSIMS 50L) available through the Center for Microanalysis.
- *Fram High Performance Computing (HPC) Cluster.* Fram is a (HPC) Cluster composed of 314 HP SL390 computer nodes with 12 cores available per node. The cluster is connected with a low latency, high bandwidth network called InfiniBand. In addition to the traditional computer nodes, it also has 60 GPU based nodes with a total of 180 Nvidia M2090 GPUs. This filesystem can perform at around 9.5 GB/s. Fram is the latest of many clusters used for analysis and simulation of climate dynamics.

Additionally, Caltech collaborates with the Naval Postgraduate School's Center for Interdisciplinary Remotely Piloted Aircraft Studies (Monterey, California). This center operates research aircraft for atmosphere science studies, including a Twin Otter aircraft that carries state-of-the-art instruments to measure atmospheric aerosol and cloud properties in situ. Faculty, students, and staff in the ESE program also have access to the supercomputer facility of the Division of Geological and Planetary Sciences, where they carry out simulations of dynamical processes in the atmosphere and oceans and of chemical reactions and transport processes affecting atmospheric chemistry.

GEOLOGICAL AND PLANETARY SCIENCES

Students and faculty in the Division of Geological and Planetary Sciences study Earth and the planets to understand their origin, constitution, and development, and the effect of the resulting physical and chemical environments on the history of life and on humanity. The approach to these problems relies strongly on the basic sciences. Programs of study and research are pursued in environmental science and engineering, geobiology, geochemistry, geology, geophysics, and planetary science. The curriculum is flexible so that students with degrees in biology, chemistry, engineering, or physics may carry out

graduate work within the division, and interdisciplinary studies are encouraged.

Southern California provides an excellent natural laboratory for the study of geology, tectonics, and earthquakes. Current advances in understanding the dynamic motions of Earth's interior have opened new opportunities for the study of crustal motions and earthquakes. Historic records of seismic activity are put into long- term perspective by studies of surface and bedrock geology. The dynamics and geometry of crustal movements are studied on local, regional, and global scales in order to understand the evolution of continents, subduction zones, and mid-ocean ridges. The division maintains active field programs in diverse areas in North America and throughout the world.

The events that shaped Earth can be identified by studying the structure of rocks and their chemical and isotopic compositions. The absolute chronology of Earth and solar system history can be established by measurements of radioactive isotopes. These geological events have been intimately associated with the origin and evolution of life on Earth. The field of geobiology uses both geological and genetic evidence to examine the impact of life on Earth and the impact of geological conditions on biology. The field of geochemistry includes studies of radiogenic and stable isotopes, petrology, chemical oceanography, and atmospheric chemistry. These tools are applied to the origins of igneous and metamorphic rocks, evidence of past climate change, tracing anthropogenic influences on Earth, and the structure of planetary interiors. The comparative study of the other planets—their atmospheres, surfaces, and internal structures—is important in our understanding of Earth and its place in the cosmos. The early history of the solar system can be approached by studies of extraterrestrial materials, including lunar samples, interplanetary dust grains, and meteorites.

PHYSICAL FACILITIES

The division is housed in four adjacent buildings, which are well equipped for modern instruction and laboratory work. They contain several seminar rooms and a library as well as student and faculty offices. Numerous computers are distributed throughout the division, including a facility for geographic information systems and remote sensing. Rock and mineral collections and sample preparation areas are available. There are modern laboratories equipped with a scanning electron microscope and electron microprobe; a variety of plasma-source, gas-source, thermal emission, and secondary ion mass spectrometers; optical-, infrared-, and Raman spectrometers; high-temperature furnaces and high-pressure apparatus including piston-cylinder, multi-anvil, diamond anvil, shock-wave facilities, and the Bruce Murray Laboratory for Planetary Visualization. Cooperation with other departments on campus provides access to additional instrumentation for sample preparation and analysis.

Laboratories for molecular geobiology provide capabilities for culturing, manipulating, and studying a wide range of environmental microbes, including anaerobes. A sensitive magnetometer facility is

designed for the study of both biomagnetism and paleomagnetics. The Seismological Laboratory, housed in the GPS division, operates the Southern California Seismic Network jointly with the U.S. Geological Survey. The network records and analyzes real-time earthquake data from more than 380 seismic stations located across Southern California. Data from the network are available for research via the Southern California Earthquake Data Center.

The Jet Propulsion Laboratory, NASA's lead center for planetary exploration, is located seven miles from campus and is administered by the Institute. Students and faculty participate in JPL activities through joint research, instrument development, mission operations, and data analysis. In addition, Caltech owns and operates several optical and radio observatories that are used partly for planetary research. Active programs of planetary studies are pursued at the Owens Valley Radio Observatory, Palomar Mountain, and the Keck Telescopes and, in the near future, the Thirty-Meter Telescope project.

HISTORY AND PHILOSOPHY OF SCIENCE

The program in history and philosophy of science is devoted to the study of the historical evolution and philosophical underpinnings of the physical and biological sciences. Work in history and philosophy of science may be pursued as an undergraduate option, a graduate minor, or on a course-by-course basis. Historical research in the program includes the origins of experimental practice, the social and institutional contexts of science, the origins and applications of quantitative methods, specific developments since antiquity in physics, biology, and chemistry, as well as biographical and comparative studies. Philosophical research in the program deals with issues in causation, explanation, scientific inference, the foundations of probability and decision theory, philosophy of mind, psychology and neuroscience, and scientific fraud and misconduct.

HUMANITIES

English at Caltech spans the major periods of American and British writing. Students can pursue interests ranging from Shakespeare and a survey of drama to romantic and modern poetry; from early fiction to the postmodern novel.

History at Caltech examines the Western and non-Western past to understand the evolution of culture, science, institutions, and behavior. Courses span the medieval, Renaissance, and modern periods; the United States, Europe, and Asia; and special topics such as radicalism and demography. In certain courses, quantitative methods drawn from the social sciences are applied to historical studies.

Philosophy is concerned with the most fundamental issues involving the nature of the world and of human knowledge, values, and judgment. At Caltech, particular emphasis is placed on philosophy of the natural and social sciences, scientific inference, and philosophy of

mind, psychology and neuroscience. In addition to survey courses we offer courses on more focused topics, including causality, probability, quantum mechanics, space-time, free will, consciousness, and on ethical questions raised by modern science and technology.

Visual culture at Caltech encompasses the study of art history, film, media, and scientific images. Students work to gain visual literacy, and to understand both the history of images humans may have been looking at for hundreds or even thousands of years, and the provenance, location, and nature of the images we see now in our every day lives. Some visual culture classes make use of the resources of the Huntington Library, Art Museum, and Botanical Gardens; the Los Angeles County Museum of Art; and other museums in the area.

Courses in English, history, philosophy, and visual culture are given at both introductory and advanced levels.

A variety of courses in music, writing, and in foreign languages, literature, and culture are also available.

AREAS OF RESEARCH

The English faculty, interested in new approaches to studying their subject, engage in research into the relationships between literature and the pictorial arts, literature, and history, and the material production of literature.

Research in history covers a wide range of historical fields and methodologies. Topics include an examination of the development of racial attitudes and behavior in the 19th-century United States; the history of the physical and biological sciences and of science in relationship to society; history and film; and political and economic development in early modern Europe. A number of faculty carry out research and teaching in the interrelated subjects of science, ethics, and public policy.

Research in philosophy includes work in philosophy of science and philosophy of mind, with particular research foci in philosophy of physics, causation, probability and decision theory, and the philosophy of neuroscience and free will.

Faculty research in visual culture focuses on a wide variety of time periods, geographic locations, and media forms but has in common a careful attention to the conditions under which objects are made, the ways in which they circulate, and the reactions they inspire in audiences.

INFORMATION AND DATA SCIENCES

The information and data sciences are concerned with the acquisition, storage, communication, processing, and analysis of data. These intellectual activities have a long history, and Caltech has traditionally occupied a position of strength with faculty spread out across applied mathematics, electrical engineering, computer science, mathematics, physics, astronomy, economics, and many others disciplines. In the last decade, there has been a rapid increase in the rate at which data are acquired, with the objective of extracting actionable

knowledge—in the form of scientific models and predictions, business decisions, and public policies. From a technological perspective, this rapid increase in the availability of data creates numerous challenges in acquisition, storage, and subsequent analysis. More fundamentally, humans cannot deal with such a volume of data directly, and it is increasingly essential that we automate the pipeline of information processing and analysis. All areas of human endeavor are affected: science, medicine, engineering, manufacturing, logistics, the media, entertainment. The range of scenarios that concern a scientist in this domain are very broad—from situations in which the available data are nearly infinite (big data), to those in which the data are sparse and precious; from situations in which computation is, for all practical purposes, an infinite resource to those in which it is critical to respond rapidly and computation must thus be treated as a precious resource; from situations in which the data are all available at once to those in which they are presented as a stream.

As such, the information and data sciences now draw not just upon traditional areas spanning computer science, applied mathematics, and electrical engineering—signal processing, information and communication theory, control and decision theory, probability and statistics, algorithms—but also a range of new contemporary topics such as machine learning, network science, distributed systems, and neuroscience. The result is an area that is new, fundamentally different from related areas like computer science and statistics, and that is crucial to modern applications in the physical sciences, social sciences, and engineering.

The Information and Data Sciences (IDS) option is unabashedly mathematical, focusing on the foundations of the information and data sciences, across its roots in probability, statistics, linear algebra, and signal processing. These fields all contribute crucial components of data science today. Further, it takes advantage of the interdisciplinary nature of Caltech by including a required set of application courses where students will learn about how data touches science and engineering broadly. The flexibility provided by this sequence allows students to see data science in action in biology, economics, chemistry, and beyond.

In addition to a major, the IDS option offers a minor that focuses on the mathematical foundations of the information and data sciences but recognizes the fact that many students in other majors across campus have a need to supplement their options with practical training in data science.

INFORMATION SCIENCE AND TECHNOLOGY

Information science and technology (IST) is a multidivisional research area that includes participants from the biology, chemistry and chemical engineering, engineering and applied science, humanities and social sciences, and physics, mathematics and astronomy divisions. Areas of emphasis include networking and distributed systems, neuromorphic engineering and sensory-based machines,

quantum computation and communications, molecular electronics and biochemical computing, biological circuit design, information flow in economic and social systems, and mathematical foundations of information.

PHYSICAL FACILITIES

IST is mainly centered around the Annenberg Center for Information Science and Technology and the Moore Laboratory. Research centers associated with IST include the Lee Center for Advanced Networking, the Center for Neuromorphic Systems Engineering, the Center for Biological Circuit Design, the Center for the Mathematics of Information, the Center for the Physics of Information, and the Social and Information Science Laboratory.

INTERDISCIPLINARY STUDIES PROGRAM

Interdisciplinary studies offer an educational alternative for undergraduates whose goals cannot be satisfied with a normal undergraduate option. The student gathers a two-person faculty committee, representing at least two divisions of the Institute, and chooses their own scholastic requirements under this committee's supervision. Approval must also be obtained from the Curriculum Committee, a standing committee of the faculty. The interdisciplinary studies program has no facilities of its own. Areas of study and research may be selected from any part of the Institute. (For a complete description, see Interdisciplinary Studies Program.)

MATERIALS SCIENCE

Materials scientists study relationships between the properties of materials and their internal structure, and how this structure can be controlled. Our multidisciplinary faculty, students, and postdoctoral scholars create new materials and take rigorous approaches to understand and control the properties of materials and their structure. From batteries and solar cells to electronic devices at the micro- and nano-scales, our department is at the forefront of scientific discovery and new technologies.

AREAS OF RESEARCH

The current areas of research by the materials science faculty include a broad range of materials, some far removed from their equilibrium thermodynamic states. Examples of such materials include metallic glasses, thin films, two-dimensional solids, quantum materials, porous and architected solids, energy-storage materials, nanostructured materials, and materials for photovoltaics and electronic devices. The physical characteristics of interest span a wide range of mechanical, thermodynamic, electrical, magnetic and electrochemical properties.

PHYSICAL FACILITIES

Research by the faculty, graduate students, and advanced undergraduates is conducted in the W. M. Keck Laboratory, the Harry G. Steele Laboratory, and frequently in the Kavli Nanoscience Institute (KNI) Laboratory, a core cleanroom facility dedicated to nanofabrication and characterization. The KNI Lab and its technical staff provide training and access to advanced instrumentation that support the nano- and microfabrication process from beginning to end. This includes resources for electron and ion beam lithography; optical lithography; thin-film and chemical vapor deposition; metal and oxide evaporation; dry etching; metrology including a spectroscopic ellipsometer; a suite of microscopes, such as focused ion beams (FIB), scanning electron microscopes (SEM) with energy dispersive spectroscopy, and AFM. The KNI also manages a transmission electron microscopy (TEM) facility which houses a 300-keV scanning TEM instrument with high resolution and analytical capabilities.

Additional facilities for the characterization of materials include X-ray powder diffractometers with position-sensitive detectors. Material-preparation facilities include equipment for additive manufacturing, physical vapor deposition under ultra-high vacuum conditions, arc melting, induction melting, casting, rapid solidification, processing of ceramic powders, and high-energy ball milling. More specialized instruments include impedance spectrometers for transport and dielectric measurements, Mössbauer spectrometers, differential scanning calorimeters and differential thermal analyzers, thermogravimetric analyzers, and gas adsorption analyzers.

In addition to the general-use equipment within materials science, a wide range of mechanical and microstructural characterization facilities are available elsewhere at Caltech including a scanning electron microscope with electron backscatter detectors, an electron probe micro-analyzer, mechanical testing machines, nanoindenters, an in-situ mechanical deformation instrument, AFM, electrochemical instrumentation, and an electrical probe tester.

MATHEMATICS

AREAS OF RESEARCH

Students in mathematics have the opportunity to work in many fields of current research. The main active areas of research by the faculty include the following:

- *Algebra.* Finite group theory, algebraic groups, representation theory, symmetric functions, algebraic K-theory.
- *Algebraic Geometry.* Moduli spaces, birational geometry, Hodge theory, Calabi-Yau varieties, arithmetic geometry.
- *Analysis.* Classical real and complex analysis, harmonic analysis, functional analysis and operator theory, orthogonal polynomials; complex, smooth, and random dynamical and Hamiltonian systems, fractals, integrable systems, partial differential

equations.
- *Combinatorics.* Combinatorial designs and matrix theory, coding theory, extremal set theory.
- *Geometry and Topology.* Low-dimensional topology, hyperbolic geometry, geometric group theory and foliations; symplectic geometry and topology, topological gauge theory, knot theory, and their interface with theoretical physics.
- *Mathematical Logic.* Set theory and its interactions with analysis, combinatorics, dynamical systems, and model theory.
- *Mathematical Physics.* Schrödinger operators, random matrices.
- *Noncommutative Geometry.*
- *Number Theory.* Algebraic number theory, automorphic forms, Shimura varieties, Galois representations, and L-functions.

PHYSICAL FACILITIES

The mathematics department is housed in the Ronald and Maxine Linde Hall of Mathematics and Physics and the W.K. Kellogg Radiation Laboratory. In addition to offices for the faculty and graduate students, there are classrooms, conference rooms, discussion areas, a lecture hall, and a lounge for informal gatherings of the students and staff. The mathematics collection is housed nearby in the Sherman Fairchild Library.

MECHANICAL ENGINEERING

Mechanical engineering at Caltech explores the boundaries between traditional disciplines of science and engineering in order to develop a fundamental understanding of interdisciplinary challenges and create advanced technology to address contemporary problems. Mechanical engineering encompasses three broad areas: (1) mechanics of materials, (2) systems and control, and (3) thermal sciences and fluid dynamics.

The educational program in mechanical engineering prepares students for research and professional practice in an era of rapidly advancing technology. It combines a strong background in the basic and engineering sciences with an emphasis on addressing the critical technological challenges of the day. It strives to develop professional independence, creativity, leadership, and the capacity for continuing professional and intellectual growth.

AREAS OF RESEARCH

- *Mechanics of Materials.* Studies in the field of mechanics of materials emphasize a fundamental understanding of mechanical behavior and failure of materials as well as its applications. Areas of interest include static and dynamic deformation and failure of homogeneous and heterogeneous solids, mechanical behavior of nanostructures, active materials, microstructure characterization, and evolution, thin films, micro-electro-mechanical systems (MEMS), composites, fracture and frictional sliding of solids, earthquake source processes, seismo-mechanics,

geomechanics, and granular media. Most problems emphasize bridging temporal and spatial scales and the development of advanced analytical, computational, or experimental techniques.

- *Systems and Control.* This area combines a broad range of mechanical engineering fields, including control systems, dynamics, kinematics, and mechanical design, as well as cross-disciplinary areas such as signal processing, computer control, engineering computation, electromechanical design, micro-electro-mechanical systems (MEMS) design, and bioengineering. General areas of interest include control theory, estimation theory, decision theory, and robotics.
- *Thermal Sciences and Fluid Dynamics.* This area encompasses experimental and computational research in fluid dynamics, heat and mass transfer, thermodynamics, and combustion. Specific research areas include Stokesian dynamics, granular materials, cavitation and multiphase flow, turbulent combustion, explosion dynamics, and flow-generated sound. Applications cover a range of scales from molecular to high Reynolds number flows. They include constitutive modeling of colloidal dispersions, micro/nanofluidic systems including Marangoni and thermocapillary forcing in thin liquid films, the formation of pollutants from combustion hydrocarbon fuels, instabilities of complex, reacting flows, and high-speed flows with shock waves. Inter-disciplinary activities in the group include research on geophysical phenomena, biomedical devices, bio-inspired propulsion, and the application of control theory to fluid mechanics.

PHYSICAL FACILITIES

Students and faculty in mechanical engineering conduct research in laboratory facilities in a number of areas, including design and prototyping, flow visualization, heat transfer, robotics, bio/nano-mechanics, nano-mechanical testing, seismo-mechanics, biomolecular circuits, autonomous vehicles, explosion dynamics, T5 hypervelocity flow, and geomechanics. A number of High-Performance Computing (HPC) clusters are available, including both CPU- and GPU-based architectures. Kavli Nanoscience Institute (KNI) is utilized for micro- and nano-fabrication, testing, and characterization.

The Jim Hall Design Lab (The Lab) is a 5,000-square-foot machine shop and maker space facility available to students, faculty, and staff of the Caltech Community. The lab facility trains students on various tools and machines ranging from conventional manual devices, such as lathes and mills, to the most modern technologies, including computer numerically controlled (CNC) Mills, Lathes, Laser, Water Jets cutters, and 3D printers. The physical workspace and its full suite of tools enable students to formulate and draft engineering concepts using computer-aided design (CAD) software and assemble actual working prototypes from metals, plastics, and the latest in high-strength composites. As engineers in training, our students' lab experience provides a "hands-on" aspect to their educational

background, complementing their foundational engineering coursework. The mission of our lab facility is to enable our students to gain valuable technical and project management experience and prepare them for the next phase of their careers.

The undergraduate lab facility is a state-of-the-art, 950-square-foot teaching laboratory located in the Gates-Thomas building. The lab space contains an axial-torsional (25kN) material test frame, strain gage measurement system, air-isolated optical table, and 2D Digital Image Correlation (DIC) optical metrology for full-field 2D visualization and quantification of mechanical deformation and strain in engineering materials. The lab facility also includes a 20 cm x 2cm x 2m water tunnel with an integrated laser particle image velocimetry (PIV) system for full-field visualization of 2D velocity flow fields. The primary mission of this lab facility is to support the Experiments and Modeling in Mechanical Engineering (ME50 ab) course sequence, which is offered each year during the winter and spring quarters. ME50a, taken during the winter term, introduces our students to Computational Fluid Dynamics (CFD) and experimental fluid mechanics. ME50 b, taken during the spring term, introduces our students to Finite Element Analysis (FEA) of engineering structures and experimental solid mechanics. Students gain hands-on experience in both parts of the course sequence as they work through each phase of a lab experiment, data collection, and post-processing of the experimental through Matlab. Technical writing skills are also reinforced through individual reports that students must independently draft and submit for each modeling assignment and lab project.

MEDICAL ENGINEERING

The Andrew and Peggy Cherng Department of Medical Engineering at Caltech focuses on the applications of micro-/nanoscale engineering sciences and technologies to the design, analysis, and implementation of diagnostic, therapeutic, and monitoring devices for translational medicine.

AREAS OF RESEARCH

- *Affordable Medical Devices and Technologies* (Burdick, Gao, Gharib, Hajimiri, Ismagilov, Scherer, Yang) Chairs for children with cerebral palsy, bed-sore mitigation, toxic material filters, saliva-based diabetes tests, handheld diagnostic devices, and remote medical tracking systems. Devices that provide freedom from disability.
- *Artificial Intelligence* (Anandkumar, Bouman, Yang) Generative AI, deep neural network, instrument-AI codesign.
- *Biomaterials* (Gao, Greer, Ismagilov, Shapiro, Tai, Zhang) Biocompatible medical materials, nanoscale-engineered smart materials, device-tissue interface, and cell-material interactions.
- *Biomechanics & Bio-Inspired Design* (Burdick, Colonius, Gao, Greer, Gharib, Shapiro, Zhang) Bio-inspired self-propulsion technologies, control systems, optimization techniques, shape

morphing, cardiovascular mechanics, biomolecular nanomechanics, and muscle and membrane mechanics.

- *Biomolecular, Cellular and Gene Therapies* (Shapiro, Gradinaru) Immunotherapy, viral vectors, probiotics, regenerative medicine, targeted molecular therapies, and therapeutic gene circuits.
- *Medical Diagnostic, Monitoring, and Therapeutic Implants* (Emami, Gao, Scherer, Tai, Zhang) Microscale implants with new functionalities to interface intact tissues and/or to replace defective functions: retinal implants, spinal cord implants, ECG implants, cardiovascular implants, implantable pressure sensors, glucose sensors, drug delivery pumps, and implantable bio-analyte sensors.
- *Medical Diagnostic and Monitoring On-Chip Devices* (Emami, Hajimiri, Ismagilov, Scherer, Yang) Magnetic spectroscopy, bioassay, and drug-screening platforms, micro-PCR and sequencer, and on-chip bio-sensors.
- *Medical Imaging and Sensing* (Bouman, Colonius, Emami, Faraon, Gao, Gharib, Hajimiri, Scherer, Shapiro, Wang, Yang) Medical photonics and sensors, advanced imaging technologies, micro flow-field imaging, computational image analysis, lensless microscopy-on-a-chip, diagnostic and therapeutic ultrasound, and shock waves, single-molecule detection and diagnostics, machine-learning enabled automated pathology analysis, magnetic spectroscopy, tera-hertz imaging, Raman spectroscopy, photoacoustic tomography, thermoacoustic tomography, optical time reversal (wavefront shaping/engineering), compressed ultrafast photography, holographic microscopy, non-invasive label-free biomedical imaging and magnetic resonance imaging, wearable biosensors.
- *Medical Nanoelectronics* (Emami, Hajimiri, Zhang) Integrated nanoelectronics and circuits for medical applications, extremely low power medical electronics and sensors, high bandwidth wireless communication devices, self-healing circuits and systems, on-chip tera-hertz sources, and systems-on-a-chip.
- *Micro/Nano Medical Technologies and Devices* (Burdick, Emami, Faraon, Gao, Gharib, Greer, Hajimiri, Ismagilov, Scherer, Shapiro, Tai, Wang, Yang, Zhang) Biochips, bio-MEMS/NEMS, micro-/nano-fabrication, holographic microscopy, and photoacoustic microscopy for medical applications.
- *Molecular and Cellular Imaging and Theranostics* (Shapiro, Wang) Contrast agents, reporter genes, biosensors, cell-based diagnostics, theranostics.
- *Nano & Micro Fluidics* (Gao, Gharib, Ismagilov) Micro-/nano-fluidics, drug delivery, and physiological machines.
- *Prosthetics* (Burdick, Emami, Tai, Zhang) Neural prosthetics and direct brain-machine interfaces, human prosthetics for paralysis, pure-thought-based control of external electromechanical devices, computer-decoding algorithms for direct brain interface, and robotic fingers.
- *Quantum Imaging and Physics* (Wang) Quantum entanglement, quantum (sub-shot noise and super-resolution) imaging, and

atomic physics.

- *Wireless Medical Technologies* (Emami, Hajimiri, Gharib, Scherer, Shapiro, Tai) Wireless communications through skins and tissues for medical electronic implants, electrograms, wireless power transfer, and biotic/abiotic interfaces.

MICROBIOLOGY

Microbiology recognizes that microbial inventions have profoundly shaped every aspect of the biosphere and geosphere throughout Earth's history. Many important molecular and cellular processes in eukaryotes are now known to have first arisen in bacteria and archaea, and microbial metabolic activities control numerous geochemical cycles. Microorganisms have served and will continue to serve as model systems in many areas of science, ranging from basic biology and biochemistry, to the understanding of physical principles governing biological systems, to emerging questions of robustness, stability, and design in complex networks. Interactions among microbes within communities, as well as interactions between microbial communities and their environments, are poorly understood. Yet studying these interactions is key to understanding fundamental relationships in nature, such as: 1) the feedback loops connecting microbial activities in aquatic or terrestrial habitats with changes in composition of the atmosphere, hydrosphere and geosphere, and 2) the symbiotic associations that sustain diverse forms of life today. For example, the interactions between a mammalian host and its microbiota are essential to the host's normal functioning and development, not merely the cause of infectious disease. Due to their metabolic versatility, microorganisms are likely to emerge as key engineering components for solving global societal problems, ranging from human health, to energy, to providing clean water to more than one billion people who currently live without it.

Caltech's version of microbiology is unique. Diverse faculty from four divisions (BBE, CCE, GPS, EAS) work together to train students in how to understand microbial systems at various spatial and temporal scales: from the molecular to the global, from the present to the past. This interdisciplinary training involves study of molecular and cellular biology, physiology, chemistry, ecology, and quantitative reasoning.

NEUROBIOLOGY

Understanding the brain remains one of the great intellectual challenges for science. To grasp the function of this marvelous organ, one needs to investigate structures, mechanisms, and dynamics that span across many spatial and temporal scales. For example, when we hear a sound, our brain is sensitive to time delays of just a few microseconds, yet the memory of that sound can last a lifetime—11 orders of magnitude longer. The span is similar in the spatial domain. The sheer number of nerve cells in the brain, approximately 1,011, suggests a coarse-grained treatment that glosses over the details of

the individual neurons, yet a single nerve cell and even a single molecule can play a decisive role. For example, activation of a single light receptor in our eye leads to a visual percept that can ultimately direct our behavior.

Neurobiology at Caltech does, indeed, span this range. Our laboratories work on the molecular structure and function of channels and receptors; the integration of such molecules into signaling organelles like the synapse; the structure and function of single neurons; the integration of neurons of diverse types into circuits; and the collective function of these circuits in controlling behavior, perception, memory, action, cognition, and emotion. Another area of emphasis concerns the developmental mechanisms by which these structures form: the differentiation of neurons in early life, the genetic mechanisms that guide their synaptic wiring plan, and how subsequent experience modifies these connections. There is also increasing interest in leveraging the basic neurobiological insights to an understanding of brain disorders. Finally, Caltech's traditional strength in engineering stimulates the development of new methods for brain science: from optical techniques to new twists of genetic engineering, to novel multi-electrode devices, to computational models and theories.

To further explore the range of brain research at Caltech—and enjoy some colorful pictures—please visit the neurobiology option website.

PHYSICS

AREAS OF RESEARCH

Students in physics will find opportunities for research in a number of areas where members of the faculty are currently active, including those listed below. Physics research at Caltech is often done in collaboration with scientists in the departments of applied physics, astrophysics, planetary science, engineering, chemistry, biology, and other departments, as well as with collaborators at other universities and laboratories. Additional research programs and more detailed information can be found on the Caltech physics department website.

- *Experimental Elementary Particle Physics.* Activities in elementary particle physics are aimed primarily at discovering new particles and interactions beyond the Standard Model (BSM) complemented by precision measurements of SM processes. Experimental efforts employ hadronic colliders and electron, muon, and neutrino beams at several international facilities. Current experiments include:
    - CMS searching for dark matter and other new particles and new symmetries up to the mass scale of several TeV at the Large Hadron Collider at CERN
    - the NOvA and DUNE long baseline experiments at Fermilab, studying the pattern of masses, mixing and CP violation in

the neutrino sector
    - the Mu2e experiment, searching for physics beyond the standard model in charged lepton flavor violation
    - a nascent effort to search for accelerator production of dark matter called LDMX
    - the long-running SuperCDMS effort to directly detect scattering of galactic dark matter with normal matter.
- *Theoretical Elementary Particle Physics.* The particle theory group studies the unification of interactions based on string theory, the detailed properties of hadrons described by QCD, the quantum properties of black holes, the foundations of cosmology, including dark matter and dark energy, and other aspects of mathematical physics.
- *Condensed-Matter Physics.* Areas of interest include correlated electron systems, topological quantum matter, quantum dynamics, disordered systems, phase transitions, atomic and excitonic Bose condensation, nanomechanical and nanoelectronic systems, biosensors, quantum electromechanics, phonon physics, high-temperature superconductivity, graphene and carbon nanotube systems, quantum entanglement, dynamics of disordered systems, chaos, pattern formation, and systems far from equilibrium. Resources include numerous labs in the Caltech physics department, at the Kavli Nanoscience Institute at Caltech, and at the Jet Propulsion Laboratory.
- *Quantum Optics and Information.* Research on campus and at the Institute for Quantum Information and Matter at Caltech includes studies of the nature of quantum computation and quantum information, cavity quantum electrodynamics, algorithms and error correction techniques in quantum computation, and generally how quantum physics can be harnessed to improve the acquisition, transmission, and processing of information.
- *Experimental Atomic/Molecular/Optical Physics.* Experimental atomic, molecular, and optical (AMO) research at Caltech focuses on controlling and understanding complex quantum systems for a wide variety of scientific goals. Current experiments include building arrays of ultracold atoms to study quantum information, metrology, many-body physics, and simulation of condensed matter systems; precision measurements in cold and ultracold polar molecules to search for fundamental symmetry violations; engineering atom-light interactions in photonic crystals; quantum physics of mechanical devices, hybrid superconducting quantum circuits, and optomechanical sensors; neurophotonics and neuromolecular sensing; development of quantum networks and communication and addressing fundamental questions in quantum information. Many of these research strands are collaborative efforts supported by the Institute for Quantum Information and Matter.
- *Nuclear Physics.* The interests of the nuclear group focus on performing precision measurements to search for new physics beyond the Standard Model. In particular, precision

measurements of free neutron decay allow sensitive searches for new physics, while measurements of the neutron electric dipole moment may help explain the dominance of matter over antimatter in the universe.

- *Astrophysics.* Research in this area covers a broad range of topics using observational tools covering the entire electromagnetic spectrum.
  - The high-energy astrophysics group at the Space Radiation Laboratory (SRL) uses X-ray and gamma-ray detectors aboard spacecraft and balloons to investigate energetic processes from compact astrophysical objects, including gamma-ray bursts from neutron-star and black-hole systems, supernova and hypernova dynamics, and the development of stars and galaxies in the early universe.
  - The cosmic ray group at SRL uses data from a variety of spacecraft to study the composition of energetic particles arriving from the sun, the local interstellar medium, and beyond, in order to understand the origin and acceleration of energetic particles in space.
  - The millimeter/submillimeter astronomy group, with collaborators at the Jet Propulsion Laboratory, studies the solar system, star and planet formation, the interstellar medium, galaxies, galaxy clusters, and the epoch of reionization using data from the Caltech Submillimeter Observatory (CSO) and other facilities. Future-oriented programs include the development of new superconducting detector technologies and instruments for use at these wavelengths, also in collaboration with JPL, and an effort to move the currently idle CSO to a new, more sensitive site.
  - The Galactic compact objects astrophysics group studies black holes, neutron stars, and white dwarf systems, including gravitational wave sources detectable by future space missions such as LISA. The group uses telescopes at Palomar, Kitt Peak and the Keck Observatory, as well as the radio telescopes of the NASA Deep Space Network.
- *Theoretical Astrophysics.* The TAPIR (Theoretical Astrophysics Including Relativity) group carries out research on an ever-changing list of topics, including planets; stars, neutron stars, black holes and their interactions; gravitational-wave astrophysics; cosmology; the formation of stars and galaxies; and numerical and analytical general relativity.
- *Cosmology.* The observational cosmology group explores the structure and dynamics of the early universe using precise measurements of the cosmological microwave background radiation and large scale structures from detectors on the ground, on balloons, and on spacecraft. Efforts to directly detect dark matter are also underway. These experiments include an active program of detector development in collaboration with scientists at the Jet Propulsion Laboratory. Theoretical studies seek to understand the large-scale structure of the universe, including the physical nature of dark matter and dark energy.

- *Gravitational-wave Physics and Astrophysics.* Observations from the (current) LIGO and (future) LISA projects are used to detect and analyze gravitational radiation to study a variety of astrophysical sources. Theoretical studies are aimed at developing sensitive data analysis techniques and calculating gravitational-wave signals from sources such as coalescing black holes and neutron stars.

PHYSICAL FACILITIES

The physics and astrophysics departments and laboratories are mainly housed in six buildings on campus: the Norman Bridge Laboratory, the Alfred P. Sloan Laboratory of Mathematics and Physics, the W. K. Kellogg Radiation Laboratory, the George W. Downs Laboratory of Physics, the C. C. Lauritsen Laboratory of High Energy Physics, and the Cahill Center for Astronomy and Astrophysics. Off-campus astronomical facilities include Palomar Observatory, the Keck Observatories, Owens Valley Radio Observatory, the Caltech Submillimeter Observatory (currently idle), and the Laser Interferometer Gravitational-wave Observatory (LIGO).

SCIENTIFIC AND ENGINEERING COMMUNICATION

The Engineering and Applied Science (EAS) Division offers a program of study in Scientific and Engineering Communication that prepares students to engage with a variety of audiences and effectively communicate scientific topics. In order for engineering graduates to excel in their chosen field, they need to develop oral, written, and media communication skills, and an ability to work with a variety of stakeholders including industry leaders, policymakers, and academics. Courses in Scientific and Engineering Communication (SEC) provide opportunities for students to experiment with a variety of communication genres and in diverse environments. The program is characterized by cross-disciplinary study and authentic practical experiences in scientific communication and advocacy.

SOCIAL AND DECISION NEUROSCIENCE

The Institute offers an interdisciplinary program of study in Social and Decision Neuroscience that prepares students to conduct research on the neurocomputational basis of decision-making and social interactions. In order to carry out cutting-edge research in this area, students need to acquire in-depth understanding of computational modeling, statistical methods, systems neuroscience, neural measuring methods such as fMRI, EEG or single unit recordings, as well as adequate understanding of related methods and results from the social sciences. The program is designed for students seeking faculty jobs in neuroscience, psychology, marketing, economics, political science or finance, or industry positions in the technology,

data science, and finance fields.

AREAS OF RESEARCH

This program is characterized by interdisciplinary research at the frontier of neuroscience, psychology, economics, and political science. Examples of research topics of interest include the following:

- Computational and neurobiological foundations of simple choice in animals and humans.
- Computational and neurobiological basis of economic and political decision making.
- Neurocomputational basis of emotion and the impact on cognition and behavior.
- Neurobiological basis of social behavior in human and animal models.
- Neurobiological basis of moral judgment and decision-making.
- Applications of neuroscience to economics, finance, and political science.
- Application of neurocomputational models of decision-making and learning to psychiatric disorders.

PHYSICAL FACILITIES

Research is conducted in multiple laboratories spanning a wide range of experimental techniques—from behavioral experiments to single unit neurophysiology. Researchers also have access to two state-of-the-art facilities: the Caltech Brain Imaging Center, which contains various human and animal brain scanners, and the Social Science Experimental Laboratory, which contains state-of-the-art facilities for conducting behavioral economic experiments of group and market interactions.

SOCIAL SCIENCE

PHILOSOPHY AND GOALS OF THE SOCIAL SCIENCE UNDERGRADUATE CORE

The social science core curriculum initiates students in the study of how humans organize, decide, govern, and allocate their resources. It teaches students how to analyze and reason about individual behavior, markets, and other institutions. Our curriculum covers methods, as well as substance. The issues facing our students in the future will be different from those that are current, but the analytical principles and methodology needed to understand those problems will likely remain the same, albeit improved. Thus, the social science core curriculum provides students with the knowledge and tools to, in the words of the catalog, “navigate the societal, political, and economic factors that influence, and are influenced by, their work.”

The objectives of the social science core curriculum can be broken into three broad categories of courses: introductory courses that teach basic principles; methods courses that seek to transmit skills and

analytical tools; and courses exposing students to substantive ideas and problems in the social sciences. More concretely: “Fundamental ideas and principles” classes expose students to a broad and introductory overview of basic ideas in economics, psychology, and political science. “Methodology and analysis” courses focus on giving students the theoretical, empirical, and data science tools to analyze problems. They cover the theoretical modeling tools most commonly used in the social sciences, as well as statistical and econometric techniques that are needed to analyze data. “Substantive problems in social science: Individuals, institutions, and markets” courses expose students to an array of substantive questions in social science, from resource allocation via markets and prices, the workings of political institutions, the consequences of poor governance, the psychological basis of human behavior, and an understanding of financial markets.

SOCIAL SCIENCE GRADUATE PROGRAM

The Caltech Ph.D. program in Social Science is highly interdisciplinary, integrating economics, political science, quantitative history, econometrics, and finance. It makes extensive use of mathematical modeling, laboratory experiments, and econometric techniques. Research in the social sciences program at Caltech strongly emphasizes the understanding and analysis of the relationships between individual incentives, collective behavior, political and economic institutions, and public policy.

AREAS OF RESEARCH

- Experimental Economics and Experimental Political Science. Caltech social scientists were among the early pioneers in the field of laboratory experimentation and Caltech has maintained a strong leadership position and research presence in the field ever since. Examples of the kinds of laboratory studies the faculty are engaged in include the behavior and design of auctions and market-like mechanisms, public goods provision and related topics in public economics, the economics of networks and matching, decision theory, inter-personal bargaining, behavioral economics, committee decision making, and electoral competition. Many of our faculty engage in laboratory experimentation as part of their research agendas in economics and political science (Agranov, Camerer, Nielsen, Palfrey, Rangel, Saito, Sprenger). A special strength of Caltech is that economic and financial theorists join in collaborations to use laboratory control in order to experimentally test theories that are otherwise difficult to test conclusively using field data (Cvitanic, Saito, Tamuz). Some of these experiments are conducted through the use of networked computers (see Facilities) in the William D. Hacker Social Science Experimental Laboratory (SSEL). Other experiments are conducted using online subject pools. The real world provides another setting for experimental research outside the laboratory, and Caltech social scientists have conducted field experiments involving a wide variety of topics, ranging from decision making in organizations, social networks, and the

behavior of different cultural groups.

- Economic Theory and Game Theory. Caltech has a strong research group in economic theory, which, together with rigorous training in statistics and econometrics forms the backbone of the core curriculum for the PhD program. Theoretical research at Caltech has played a key role in the design and practical implementation of new institutions that more efficiently allocate scarce resources and provide public goods. Some of this work has had important public policy applications. Prominent examples include the design of FCC auctions to allocate the electromagnetic spectrum for telecommunication, and the market for allocating and trading permits for pollution emissions in the Los Angeles basin. Much of this theoretical design research is complemented by experimental studies that provide a testbed for competing designs. There is an active group of faculty and graduate students working in the areas of the optimal design of contracts and markets (Cvitanic), the economics of information (Pomatto, Tamuz), decision theory (Caradonna, Pomatto, Rangel, Saito), game theory (Niemeyer, Palfrey, Pomatto, Saito, Tamuz) and matching Social Science and Research. There are several active programs for inter-action between our theory faculty in the social sciences and the faculties of computer science and applied mathematics. This is formally organized around two interdisciplinary centers, the Lee Center for Advanced Networking and the Social and Information Science Laboratory (SISL), with the latter offering a bi-weekly seminar coordinated between the computer science department and the social sciences faculty and featuring speakers in economics, computer science, game theory and related disciplines. There are many informal connections that reinforce the formal connections, including research collaborations between faculty and graduate students in these different areas.
- Political Economy and Political Science. Caltech has a long tradition of strength in research that spans the boundary of the economics and political science disciplines. Research in political economy at Caltech continues to be a major strength of the program and provides a natural bridge that unites the faculty in economics, political science, and quantitative history. The focus of research in political economy and political science at Caltech emphasizes rigorous theoretical modeling drawing heavily upon techniques from economic theory and game theory, combined with empirical studies using highly sophisticated quantitative analyses of a wide variety of data sources: experimental, survey, field, voting, and historical data. Ongoing political economy research areas of the current faculty include: the interacting forces of bargaining, voting, and communication in committees, legislatures, bureaucracies, and assemblies (Agranov, Gibilisco, Hirsch, Katz, Lopez-Moctezuma, Palfrey); the Voting Technology Project, a joint Caltech-MIT research venture, established in 2000 to evaluate and improve the performance and reliability of U.S. balloting technology, registration systems, election

administration, redistricting, and election law (Alvarez, Katz); political forces affecting judicial behavior (Hirsch), strategic voting in multi-candidate and multi-stage elections (Alvarez, Kiewiet, Palfrey), the politics of inequality and redistribution (Agranov, Palfrey) and several areas of comparative and international politics, including studies of the causes and consequences of corruption, domestic unrest, and international conflict (Gibilisco, Lopez-Moctezuma).

- Financial Economics. Caltech has built a small but very active research group in finance. The researchers in this group are working on a range of topics in mathematical finance, asset pricing and dynamic contracting (Cvitanic), behavioral finance (Camerer) and economic history of financial crises (Janas, Rosenthal). There is a regular seminar series in finance that features distinguished researchers from around the world. Caltech faculty outside the finance group itself are also engaged in empirical research in financial economics. These include experimental areas of study and research studies of asset markets (Camerer), interest rate policy making by the Federal Open Market Committee (Lopez-Moctezuma), and online credit markets (Xin).
- Behavioral Economics. Research in behavioral economics at Caltech overlaps all of the above groups. Laboratory experimental research discovers interesting behavioral anomalies and can also test theoretical models designed to account for such anomalies. On the theoretical side, much of the game-theoretic and decision-theoretic research at Caltech is motivated by experimental observations, leading to extensions or modifications of standard models. These extensions in turn suggest experimental designs that are then implemented in the laboratory by our faculty and graduate students. Faculty research in political behavior (Alvarez, Katz, Kiewiet) and behavioral finance (Camerer) are complementary and add strength more generally to understanding social behavior.
- Quantitative History. Just as with the theoretical, experimental, and empirical work using contemporary data, historical research conducted at Caltech employs mathematical modeling and sophisticated statistical techniques to attack a wide range of historical questions. Historical research conducted at Caltech addresses questions that cut across economics, political science, political economy, and finance, often combining archival work with state-of-the art statistical techniques. These include the development of capital and credit markets (Janas, Rosenthal), the evolution of wealth distribution from 1800 to the present (Rosenthal), the causes of recurrent financial crises in capitalist economies (Janas, Rosenthal), the determinants of economic and technological growth, the development of and financing for public institutions (Dennison, Janas), and the roots of the divergence between east and west Europe (Dennison).
- Applied microeconomics and econometrics. Empirical research in social science blends creative collection and analysis of field data

with rigorous application of tools and methods from econometrics and statistics. We offer courses and supervise students in these areas. A number of faculty members specialize in empirical work in a number of fields, including finance (Xin), industrial organization (Xin), political economy (Alvarez, Gibilisco, Katz, Kiewiet, Lopez-Moctezuma, Sherman), and behavioral economics (Camerer). Methodological areas of specialization include econometrics (Sherman, Xin), causal inference (Alvarez, Katz, Sherman), machine learning (Alvarez, Camerer, Katz, Xin), and Bayesian statistics (Katz).

- Social and Decision Neuroscience. A small but active group of SS do research at the intersections of neurobiology, psychology, and social sciences (Adolphs, Camerer, Mobbs, O'Doherty, Rangel). This group offers a separate PhD option (SDN) focused on the behavioral neuroscience of decision making (see the catalog entry for "Social and Decision Neuroscience"). The SDN group uses fMRI and EEG brain-imaging, invasive recording of neural firing, eye-tracking, and psychophysiology. They study how the neural circuitry of decision making in individual choice, game theoretic, and market settings can be associated with computational algorithms. Their scope includes the study of emotion, social media, and non-human animals.

PHYSICAL FACILITIES

Caltech has a state-of-the-art onsite laboratory for experimental research in economics, political science, game theory, decision theory, and financial economics: The Hacker Social Science Experimental Laboratory (SSEL, established 1998).

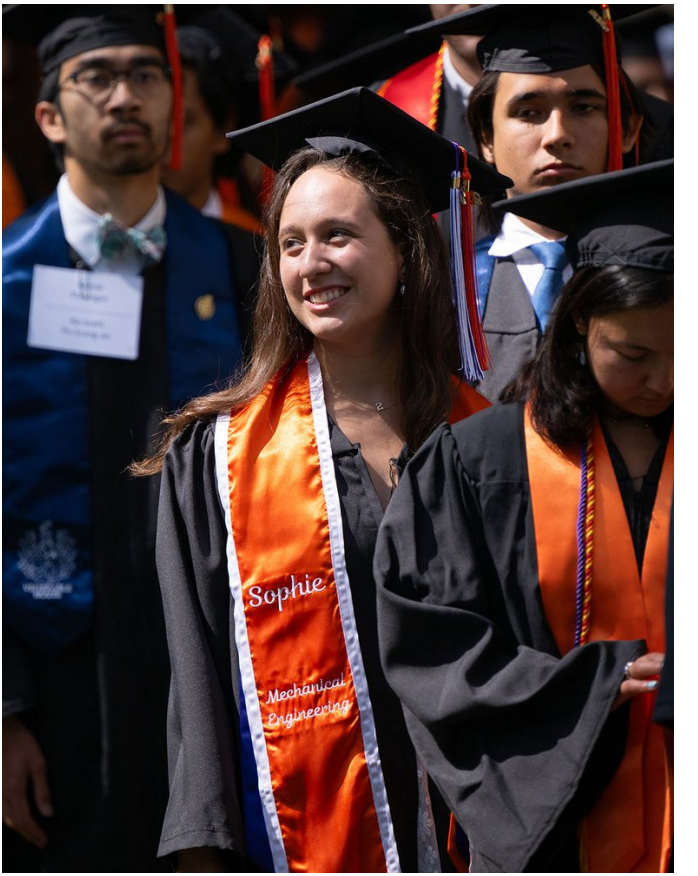
SYSTEMS BIOLOGY

Systems Biology seeks to understand how the parts of biological systems are integrated to produce the amazing machines, cells, organisms and ecosystems that exist in our world. We seek to define general principles of biological systems. Part of the effort involves defining the relevant parts and measuring how they change in a quantitative and comprehensive fashion as they carry out their functions. This task is the domain of genomics, proteomics, metabolomics, functional genomics, bioinformatics and other aspects of Network Biology and Bioinformatics. Another related task is to understand the "mechanisms," the precise structures and interactions of those parts that ultimately produce biological function. This task requires Computational Modeling of potential mechanisms, coupled with Quantitative tests of the predictions of models by cell biological, molecular biological, and biophysical techniques. One particularly stunning feature of organisms is their ability to develop from a single fertilized egg; thus, Systems Developmental Biology is an important third theme of our program. This theme involves the study of how organisms generate complexity of cell types in a defined spatial organization by a sequential, contingent, irreversible cascade of

molecular, cellular, and genomic processes.

Our goal is to train students who can seamlessly integrate diverse quantitative and experimental methodology and can balance the tension between global understanding and mechanistic insight. This training involves study of biology, mathematics, quantitative reasoning, computational and data analysis tools, and the rich experimental methods of the biological sciences.

Information for Undergraduate Students



The undergraduate program leads to a four-year Bachelor of Science degree. Admitted students matriculate in the fall term only. Caltech does not have a summer session or part-time program and cannot consider you if you already have a bachelor's degree from another college, university, or the equivalent. If you have matriculated at any college, university, or the equivalent in a program leading to any degree, you will be required to apply as a transfer student and should read the requirements in the section titled "Transfer Admissions.''

ADMISSION TO THE FIRST-YEAR CLASS

Students are admitted to the first-year class on the basis of strong academic performance in a rigorous course of college preparatory study, especially in the areas of math and science; teacher and counselor recommendations; personal characteristics; a strong demonstrated interest in math, science, or engineering; and information provided on the application. Information on the application process can be found on the admissions office website at admissions.caltech.edu. Students are encouraged to apply online through the Common App or the QuestBridge program. For further information on admission, please e-mail ugadmissions@caltech.edu. To be considered for admission, applications to the first-year class must be submitted online by November 1 for Restrictive Early Action or January 5, 2026 for Regular Decision.

APPLYING

Information on the application process can be found on the admissions office website at admissions.caltech.edu. Students are encouraged to apply online through the Common Application or the QuestBridge program. For further information on admission, please call (626) 395-6341 or e-mail ugadmissions@caltech.edu. To be considered for admission, applications to the first-year class must be submitted online by November 1 for Restrictive Early Action or January 5, 2026 for Regular Decision.

QUESTBRIDGE

Since 2008, Caltech has been a proud QuestBridge partner school. QuestBridge partners with approximately 50 institutions to connect the nation's brightest students from low-income backgrounds with leading institutions of higher education where they are given a full ride with no loan. Applications are due to QuestBridge annually at the end of September. Students are able to rank Caltech as one of fifteen institutions they'd like to attend and, if chosen as a QuestBridge Match Finalist, Caltech reviews student applications in November and matches with QuestBridge Match students on December 1 each year. For more information about QuestBridge, visit www.questbridge.org.

RESTRICTIVE EARLY ACTION

Restrictive Early Action is a non-binding option that limits the number of schools an applicant may apply to during the early period, but in return offers a student the opportunity to receive an offer of admission from their first-choice school. The Restrictive Early Action process requires that the completed application be submitted online by November 1 through the Common App. Under this application plan, students will be notified in mid-December of their admission decision. Students admitted under Restrictive Early Action have until May 1 to make their commitment to attend.

Students who choose to apply REA to Caltech may not apply Early Action nor Early Decision to any other institution, with the following exceptions:

- An institution outside of the United States;
- Any public institution that has a non-binding admissions policy with a fall application deadline (such as the University of California system);
- An institution's non-binding rolling admissions process;
- Any military academy;
- Any scholarships or special academic programs with an early deadline at another institution, public or private, if the early application submission is a necessary aspect for consideration, and the outcome is non-binding;
- If you are deferred admission after applying REA to Caltech, you may apply to another institution's Early Decision II program. If you are admitted to that institution's Early Decision II program, you are required to withdraw your application of admission to Caltech.

ACADEMIC REQUIREMENTS

Students are expected to prepare for Caltech by successfully completing the following curriculum:

- Four years of math, including one year of calculus*
- One year of physics*
- One year of chemistry*
- One year of biology (recommended)
- Four years of English
- Two years of history and/or social sciences courses (3+ years recommended)

If a student is unable to take a calculus, chemistry, or physics course in high school because it was not available to them or they experienced unresolvable course conflicts, Caltech will accept examination scores or certification showing proof of knowledge in the subject in lieu of an academic course requirement, provided both the student and their counselor document the underlying, unresolvable issue(s).

The following examinations and certificates can substitute for the course requirements for calculus, chemistry, or physics:

- A score of 5 on AP exams in AP Calculus AB, AP Calculus BC, AP Chemistry, AP Physics 1, AP Physics 2, or AP Physics C
- A score of 6 or 7 on the IB Mathematics HL; Chemistry SL or HL; or Physics SL or HL examinations. **Note, IB Mathematics SL does not meet our requirements.**
- A certification from Schoolhouse.world in one of the following courses: AP/College Calculus AB or BC; AP/College Chemistry; High School Physics or AP/College Physics 1

For the class of 2029, these are the only avenues for substituting course requirements in calculus, chemistry, and/or physics at Caltech. There will be no exceptions.

Standardized Exams

Caltech requires first-year applicants to submit either the SAT or the ACT for admissions to Caltech. For fall 2026 applicants, Caltech does not require the ACT writing or science subscores. In fairness, Caltech will not consider a student's composite score and instead, Caltech will consider each individual subscore: Math, English, Reading, Science (optional), and Writing (optional)

For more information on the standardized testing policy, visit the UGA Standardized Testing page.

SAT Subject Tests: As of January 2020, Caltech eliminated the requirement for applicants to submit two SAT Subject Tests. These sections will not be considered in the application review process.

English Proficiency Scores are required of all international students unless 1) the student's native language is English or 2) English is the primary language of instruction in the student's secondary school.

Acceptable English proficiency exams include:

- TOEFL Internet Based Test (IBT)
- IELTS
- Duolingo English Test (DET)

Essays

The essays, which are required as a part of the application, are intended to provide students the opportunity to communicate their interests, experiences, and background. Since Caltech is interested in learning about each applicant, the essays are viewed as an important part of the admission decision process. Caltech's supplemental essays are updated annually and listed on the admissions website each August 1.

Letters of Recommendation
Two letters of recommendation and a Secondary School Report are required. One letter must be from a STEM teacher (math, chemistry, physics, or biology), and one letter from a humanities or social science teacher (English, history, government, or economics). A Secondary School Report must be filled out by the applicant's secondary school counselor or other school official.

Additional Materials
Students are welcome to provide supplemental materials that they believe will help the admissions committee learn more about them. These materials may include but are not limited to:

- Research paper, abstract, or publication (citation if published, letter of evaluation, and research description required)
- STEM portfolio
- Non-STEM portfolio

After the application deadline, students will receive a link to the Caltech application portal (Beaver Breakroom), which will include instructions on submitting supplemental materials.

Acceptance
Caltech is a member of the National Association for College Admissions Counseling and therefore agrees to comply with the national candidate's reply date of May 1. Places in the entering class will not be held after May 1. Restrictive Early Action applicants will be informed of their admissions decision in mid-December and Regular Decision applicants will be informed by mid-March. Regardless of round, admitted students have until May 1 to respond to their admissions offer.

Gap Year
Caltech will consider requests from admitted students for a one-year gap year (and occasionally two-year gap years in the case of students on religious missions or doing required military service). Students who request a gap year must accept their offer of admission and then submit a written request stating the purpose of postponement to the Director of Undergraduate Admissions. Instructions are provided to admitted students annually in the Caltech applicant portal, called the Beaver Breakroom.

Advanced Placement, International Baccalaureate, and College Credit
Caltech encourages all prospective undergraduate applicants to prepare by challenging themselves with the most rigorous course of study available, including the Advanced Placement (AP) and International Baccalaureate (IB) programs. However, college credit for AP or IB classes is not automatic. Course credit and/or placement in an accelerated program is sometimes granted as deemed appropriate by the department faculty. The awarding of Caltech course credit takes place at the time of registration each fall.

Biology
Biology majors who have passed Bi 8 and Bi 9 (with 9 units on grades) are considered to have met the core requirement of Bi 1.

Chemistry
The student's qualifications for placing out of Ch 1 ab will be determined by the performance on an advanced placement examination to be administered in the summer prior to registration. Qualified students, with the instructor's consent, are allowed to substitute either Ch 8 or Ch/ChE 9 for the "core" chemistry laboratory requirement (Ch 3 a or Ch 3 x).

English/Writing
All incoming students (first-year and transfers) will take a placement assessment to determine whether they are adequately prepared for the substantial writing component that is part of all first-year humanities courses. Most new students participate in a web-based version of this assessment, which is usually conducted in early June. A makeup assessment is held just before fall classes begin. Based on results of this writing assessment, students may be required to take Wr 1 or Wr 2 in the fall quarter. (Wr 1 and Wr 2 count for general Institute credit only.) After completing these courses, students may, at the discretion of humanities faculty, be required to go on to subsequent coursework in academic writing, such as Wr 3, Wr 4, or Wr 50, before or concurrently with first-year humanities coursework. During the first week of classes, students will be required to produce an in-class writing sample to confirm the initial placement.

Mathematics
During the summer before the first year, entering first-year students are required to take the Foundations Assessment, which includes a test in basic calculus that will determine which students will be placed in a special section of Ma 1 a for those with less complete preparation, and later take Ma 1 d; if students are interested in placing out of some of the core Math series, they may also take an advanced placement examination to determine whether they will begin the mathematics core sequence at an advanced level.

Normally, an entering first-year student takes Ma 1 abc, Calculus of One and Several Variables and Linear Algebra. This course covers the calculus of functions of one and several variables; infinite series; vector algebra; basic and advanced linear algebra; derivatives of vector functions, multiple integrals, line and path integrals; and theorems of Green and Stokes. The course is divided into a lecture part and a recitation part that focuses mainly on problem-solving.

Students in need of additional problem-solving practice may be advised to take Ma 8 (in addition to Ma 1 a) in the first quarter.

Physics
The required first-year physics course, Ph 1 abc, is considerably more rigorous than most advanced placement work, and entering first-year students are encouraged to take Ph 1. All students are required to take a Physics test as part of the Foundations Assessment during the summer to aid in the organization of Ph 1; students who are interested in placing out of some of the core Physics series may also take an advanced placement examination online over the summer.

Residency Expectation
Undergraduate housing includes the eight houses (Avery, Blacker, Dabney, Fleming, Lloyd, Page, Ricketts, Venerable), the Bechtel Residence, Marks House and Braun House. First- and second-year students are required to live on campus. Caltech Accessibility Services for Students (CASS) provides the opportunity for students to request housing accommodations based on a diagnosed disability. For questions regarding this process, students should contact CASS or visit https://cass.caltech.edu/housing-accommodations.

Foundations Assessment
To help students understand their own preparation in relation to the First-Year Core, all new first-year students are required to take the Foundations Assessment, which covers principles of high school Chemistry, Physics, and Math. Taken early in the summer, the tool provides students feedback on areas essential to the Core, coordinated with summer resources that can help deepen familiarity and confidence with key topics. Additional information can be found at https://deans.caltech.edu/foundations-assessment-information

New Student Orientation
All first-year, transfer, 3/2 and exchange students are expected to attend the New Student Orientation as part of the regular registration procedure. Orientation takes place the week prior to the beginning of classes. Faculty members, staff and upperclass student leaders participate to introduce new students to the Caltech community. The orientation period provides an opportunity for new students to become acquainted with the campus, the Honor System, and other aspects of life at Caltech. In addition, they will meet classmates, upperclass students, and faculty during this time.

ADMISSION TO UPPER CLASSES BY TRANSFER

TRANSFER ADMISSIONS

Caltech admits transfer students for the fall term only. We require a completed application, letters of recommendation, an official transcript from the last secondary school attended and all colleges or universities attended, descriptions of all college-level math and science courses, and completion of the Caltech Transfer Entrance

Examinations. Please review the section titled ”Eligibility Criteria for Admission’’ to determine whether you meet the eligibility requirements for transfer admissions consideration.

Academic Preparation
The following is a list of the Caltech core curriculum, taken by all Caltech students during their first two years. It is expected that transfer students will have had exposure to mathematics and science courses on a comparable level prior to entry to Caltech. Any of the following core courses that have not been covered by incoming transfer students must be taken upon matriculation to Caltech. There are no specific topics expected to have been covered in humanities and social science classes.

An evaluation of each transfer student’s written English is required prior to registration and may result in an additional course requirement.

First-year courses:

- Mathematics 1 abc
- Physics 1 abc
- Chemistry 1 ab
- Chemistry 3 a or 3 x
- Computer Science 1
- Biology 1, 1 x, 8, or 9
- Humanities and Social Science electives
- Menu science class (see Menu Classes ; can be taken first-year or sophomore year)

Sophomore courses:

- Physics 2 abc or Physics 12 abc
- Additional laboratory science
- Humanities and Social Science electives

Note: Mathematics 3 is not required for the core curriculum, but may be required for a specific option.]

Eligibility Criteria for Admission
The Institute admits to its sophomore and junior classes a small number of students who have excellent records at other institutions of collegiate rank and who perform satisfactorily on the Caltech Transfer Admissions Entrance Examinations.

- Students must have completed their secondary school education, and have subsequently enrolled at a college or university and earned credit, in order to be considered for transfer admission.
- Transfer students are not admitted to the senior year at Caltech.
- Students who have already completed a bachelor’s degree in any subject are not eligible for transfer.

Standardized Test Requirements
Transfer applicants are not required to submit SAT scores and, during the testing moratorium through Fall 2025, Caltech will not review any SAT or ACT test scores in the admissions process.

International Student English Proficiency
English Proficiency Scores are required of all international students unless 1) the student's native language is English or 2) English is the primary language of instruction in the student's secondary school and university.

Acceptable English proficiency exams include:

- TOEFL Internet Based Test (IBT)
- IELTS
- Duolingo English Test (DET)

Evaluation of Written English
All entering transfer students will be required to undergo an evaluation of their written English prior to enrolling.

Transfer Admissions Entrance Examinations
All applicants are required to take Caltech Transfer Admissions Entrance Examinations in mathematics and physics. After a student submits their transfer application and after the February 1 deadline, the student will complete the Entrance Examination Self-Proctor Form through the Caltech applicant portal (called the Beaver Breakroom). Once the student submits this form, Caltech will send the student the exams electronically, along with instructions for uploading completed work.

Students may take the exams on their honor, adhering to Caltech's Honor Code: No member of the Caltech community shall take unfair advantage of any other member of the Caltech community.

The examinations are due February 15.

Here are some more specifics:

- Each exam has a 4-hour time limit, for a total of an 8-hour commitment. Students are not required to take both exams in one day.
- Students may only look at the examinations at the time that they take them.
- Reference materials, calculators, electronic devices, textbooks, tablets, notes, or aids are not permitted.
- If a student requires special testing accommodations, please let us know prior to the application deadline.

Cheating on the examinations only hurts the student and their ability to be successful at Caltech. The Caltech curriculum is extraordinarily challenging by design. Don't cheat.

Transfer of Credit
The courses for which enrolled transfer students will receive credit, and the corresponding class standing, will be determined at the time of enrollment. Final transcripts must be submitted to Undergraduate Admissions. Syllabi must be submitted to the Registrar, who will present the material to the faculty for evaluation. After a student is admitted, they may work with Admissions to obtain a preliminary evaluation of class standing. Preliminary class standings are not guaranteed. Actual class standing will be based upon the formal transfer credit evaluations over the summer. If the standard of work taken elsewhere is uncertain, additional examinations may be required before the question of credit is finally determined. Once a student has enrolled, faculty members review each course submitted for credit on an individual basis. Therefore, we cannot answer questions about the acceptance of coursework from other institutions prior to admission.

Graduation Requirements
Admitted transfer students must meet the following requirements in order to receive a Caltech Bachelor of Science degree.

- A Caltech undergraduate degree is based on a four-year residential experience (study abroad included) in which students have the time to explore their academic interests in a deep and rigorous way. Students who are admitted as transfer students or 3/2 students may be granted advanced standing and term credit for academic work accepted in transfer to Caltech. However, transfer and 3/2 students must enroll for a minimum of six terms at Caltech. Any exceptions must be approved by the dean of undergraduate students and the vice president for student affairs.
- Regardless of the amount of credit awarded upon matriculation, transfer students must spend at least two years (six terms) in residence at Caltech. Students must also earn at least 216 units at Caltech, not including courses taken to satisfy math and science core curriculum requirements.
- Students must take, or have taken the equivalent of, all core curriculum courses.
- Students must satisfy all of their chosen option's degree requirements. Transfer students may choose from among all Caltech undergraduate options.

Admissions Application
Applications are available by December 1. Completed applications should be received by the Office of Undergraduate Admissions by February 1. Applicants will be notified of the decisions of the Admissions Committee in early May. Information on the application process can be found on the admissions office website at admissions.caltech.edu. Students should apply online through the Caltech Application. For further information on admission, please e-mail ugadmissions@caltech.edu.

NONDISCRIMINATION AND EQUAL OPPORTUNITY

Caltech is committed to equal opportunity for all persons without regard to sex, race, creed, color, religion, national origin, ancestry, age, marital status, pregnancy, gender, gender expression, gender identity, sexual orientation, genetic information, status as disabled veteran, or other eligible veteran, for otherwise qualified individuals with a disability, or any other condition protected by the state and federal law. It is the policy of Caltech to provide a work and academic environment free of discrimination as required by federal and state law, including Title IX which prohibits discrimination based on sex in Caltech's educational programs and activities. Caltech will take all reasonable steps to eliminate discrimination, harassment, and sexual misconduct in its work and academic environment. Inquiries concerning the application of Title IX may be referred to Caltech's Title IX Coordinator, Hima Vatti, who can be reached at Equity or at 626-395-3132.

THE 3/2 DUAL DEGREE PLAN

Caltech invites students from a select group of liberal arts colleges to transfer to Caltech upon completion of their junior year. After two years in residence at Caltech, and the successful completion of our requirements, 3/2 students will be granted a Bachelor of Science degree from Caltech and a second bachelor's degree from their liberal arts college. Students may transfer into any of the Caltech options.

Students from the following institutions are eligible to apply to the 3/2 program:

Bowdoin College (ME)	Ohio Wesleyan University (OH)
Bryn Mawr (PA)	Pomona College (CA)
Grinnell College (IA)	Reed College (OR)
Haverford College (PA)	Spelman College (GA)
Mt. Holyoke College (MA)	Wesleyan University (CT)
Oberlin College (OH)	Whitman College (WA)
Occidental College (CA)	

Applications and a program description are available from the 3/2 liaison at each of the liberal arts college partners and from the Caltech Office of Undergraduate Admissions. Instructions on how to create and complete Caltech's online 3/2 application can be found at admissions.caltech.edu. All 3/2 applications and support materials must be submitted by April 1.

Admission to the 3/2 program is not guaranteed and will be determined by the Caltech Faculty Upperclass Admissions Committee. Students applying should have a record of superior academic achievement at their home institutions, and strong letters of recommendation from their 3/2 liaison and an additional faculty

member. They must have completed a minimum of one year of calculus-based physics and mathematics (two years are recommended), including multivariable calculus and differential equations, and one year of chemistry.

EXCHANGE PROGRAMS

Exchange programs exist with Occidental College and Art Center College of Design, permitting Caltech students to receive credit for courses taken at these colleges. Students from these colleges also may receive credit for courses taken at the Institute. Tuition payments are not required, but the student may have to pay any special fees. The student must obtain approval from the instructor of the exchange course. Exchange courses taken by Caltech students must have prior approval by the student's option, by the division providing courses most similar to the proposed course, and by the registrar. Students wishing to take such courses should obtain the appropriate form at the Registrar's Office, get the required signatures as above, and return it to the registrar. First-year students at Caltech ordinarily cannot participate in this exchange.

STUDY ABROAD AND AWAY

Study abroad or away allows students to experience life in other countries and regions of the United States, and to gain a broader exposure to the sciences, engineering, economics/management, the social sciences, and humanities.

Please see the Financial Aid section of this catalog for details on applying for and eligibility for financial aid related to study abroad or Study Away. Note that supplemental charges and travel should be listed by the student in their financial aid budget so that these amounts can be considered when funding is calculated.

Additional information, including application procedures and exact deadline dates, is available from the Fellowships Advising and Study Abroad Office at fasa.caltech.edu.

UNIVERSITY OF CHICAGO STUDY AWAY PROGRAM

Our newest program is an exchange with the University of Chicago. Students will spend the fall term at the University of Chicago and live in a University of Chicago hall of residence in a single room. Students are required to take at least two classes (18 units) in classes that will fulfil option requirements. Students take a maximum of 4 classes and can take up to 2 classes in the humanities or social sciences. A number of Chicago's graduate schools will be visiting undergraduates to take class. This is restricted to one class total, which is part of the maximum of 4 classes. This requires a petition that is executed after a student is nominated to the exchange and accepted by the University of Chicago and within the timeframe designated by the University of Chicago. Information on which graduate schools allow this is available in the exchange application materials.

A minimum GPA of 3.5 is required to apply. Eligible sophomores and juniors interested in either the fall or winter term should apply by the January deadline for the fall term of the next academic year. Further information, including application procedures, more about the University of Chicago exchange, and the exact deadline date, is available from the Fellowships Advising and Study Abroad Office at www.fasa.caltech.edu. More information about the University of Chicago can be found at www.uchicago.edu.

Students are required to attend the fall orientation for which a fee is charged, ~$400 to $500. The orientation takes place the week prior to the start of the fall quarter. Since the University of Chicago is on a quarter system, their fall term correponds closely to Caltech fall term dates.

Please see the Financial Aid section for details on applying for and eligibility for financial aid related to study away. Students who receive financial aid should list supplemental charges and travel in their aid application.

STUDY ABROAD

CAMBRIDGE SCHOLARS PROGRAM

The Caltech Cambridge Scholars Program offers qualified juniors and seniors the opportunity to spend the fall or winter term at the University of Cambridge in England. Students are hosted by and live in one of the Cambridge Colleges participating in the program. The participating colleges are Corpus Christi, Pembroke, St. Catharine's, and St. John's. Students pay Caltech housing, meals, tuition, and other standard Caltech fees for the term. There may be a small supplemental charge for room and tuition. The supplement varies yearly depending on prices and the exchange rate.

Students are admitted into one Cambridge department in the biological sciences, physical sciences, computer sciences, mathematics, or engineering sciences to take classes within the tripos, i.e., subject, offered by that department. Students can only take courses in one tripos subject, but can usually take classes from more than one part of the tripos in that subject. Students will find more information on the tripos structure and Cambridge University in the Fellowships Advising and Study Abroad Office or at www.cam.ac.uk.

During the term at Cambridge, students take the equivalent of at least 36 Caltech units, usually four Cambridge courses, but may take in some subjects. For their classes, students receive a minimum of 36 Caltech units that can be used to fulfill option requirements or to fulfill other Institute course requirements. Note that the final number of units and whether the units can be used to fulfill departmental requirements will be determined after faculty review upon a student's return to Caltech.

Caltech students have the use of all Cambridge facilities and are matriculated into the university for the term. A minimum 3.6 GPA is required to apply. Eligible sophomores and juniors interested in either

the fall or winter term should apply by the January deadline for the next academic year. Further information, including application procedures, and the exact deadline date, is available from the Fellowships Advising and Study Abroad Office at fasa.caltech.edu. Students can find more information about Cambridge at www.cam.ac.uk.

Please see the Financial Aid section for details on applying for and eligibility for financial aid related to study abroad. Students who receive financial aid should list supplemental charges and travel in their aid application.

COPENHAGEN SCHOLARS PROGRAM

The Caltech Copenhagen Scholars Program offers qualified juniors and seniors the opportunity to spend the fall at the University of Copenhagen (UCPH) or the Danish Technical University (DTU), both universities in the Copenhagen metropolitan area. At UCPH students will find courses offered in the physical or life sciences and computer science. At DTU students can take courses in engineering, computer science, nanotechnology, applied physics, space sciences, and in a broad range of science subjects, e.g., chemistry, physics, and mathematics. Students must select UCPH or DTU as their admitting university and will take all courses in the sciences/applied sciences at that university. All students are required to take a Danish language class during the semester.

Students live in a modern kollegiet (dormitory) with Danish students. There may be a supplemental charge for the housing due to the ~15 weeks long semester. The supplement varies yearly depending on prices and the exchange rate. Students admitted to UCPH live in a UCPH kollegiet and students admitted to DTU live in a DTU kollegiet.

There is no meal plan, but each kollegiet has a well-equipped kitchen, and students may cook for themselves or with the other students on the hall. In addition to the supplemental housing charge, all students pay for standard meals and tuition, but should budget additional funds for food due to the length of the semester. Note that while students pay Caltech meal fees, the meal fee is used to spend on food while in Copenhagen. Students can cook in their kollegiet or eat out. Caltech fees are due by the normal fall due date.

Both UCPH and DTU are on a semester system, and Caltech students attend from the last week of August to mid-December and are required to participate in the one-week orientation or advising period the last week of August. Students have a one-week vacation in mid-October, and many use this vacation week to travel in Denmark or Europe.

Students take a maximum of 30 ECTS (European Credit Transfer System) and at least two classes (18 Caltech units) must get option credit of some type. All students take a class in the Danish language offered at UCPH. Students attending Copenhagen University are required to take a course in Danish culture and two Block 1 and one Block 2 class. Students attending DTU may elect to take a class from the Danish Culture series (monarchy, film, Vikings, etc.) if it fits their

schedule and they do not exceed 30 ECTS. units combined with their DTU classes and Danish language class at UCPH.

All upper-level undergraduate or beginning graduate-level courses at UCPH and DTU can be taught in English.

Students admitted to DTU may take a class on the history of technology, which may qualify for Humanities credit. DTU has a very intriguing group of classes in management and in technology management. These can be taken for social science or option credit with the permission of the option representative.

Students receive a minimum of 36 Caltech units (many receive more units) that can be used for general or option credit or to fulfill other Institute course requirements. Note that the final number of units and whether the units can be used to fulfill departmental requirements will be determined after faculty review upon a student's return to Caltech.

Students can enroll in an optional three-week-long Danish-language course in August at either UCPH or DTU depending on their admitting university. This course is not required, but as noted, all students are required to take Danish language during the fall semester for credit.

Further information about the Copenhagen Scholars Program is available in the Fellowships Advising and Study Abroad Office and online at: www.fasa.caltech.edu. Go to www.dtu.dk or www.ku.dk for further information on DTU or UCPH. Note that UCPH is also known as KU standing for Københavns Universitet in Danish.

Please see the Financial Aid section for details on applying for and eligibility for financial aid related to study abroad. Students who receive financial aid should list supplemental charges and travel in their aid application. A minimum 3.0 GPA is required.

ÉCOLE POLYTECHNIQUE SCHOLARS PROGRAM

The École Polytechnique Scholars Program offers qualified juniors and seniors the opportunity to spend the fall, winter, or spring term at the École Polytechnique, which is located outside of Paris in the town of Palaiseau, about 40 minutes by train from Paris.

The École Polytechnique, often referred to by the nickname "L'X," is the foremost French *grande école* of engineering (according to French and international rankings). Founded in 1794 and initially located in the Latin Quarter in central Paris, it was moved to Palaiseau in 1976. It is one of the oldest and most prestigious engineering schools in the world, with a very selective entrance exam. As one of the world's foremost establishments in science education, the École Polytechnique trains graduates who become outstanding scientists, engineers, researchers, managers, and politicians.

At École Polytechnique, students can take courses in one academic area called an *approndisement*. The subjects are engineering, computer science as well as the sciences, e.g., chemistry, physics, environmental sciences (GPS students) and mathematics. Students can also take one class in the social sciences and humanities if their schedule permits. All students take a French language class. Classes are taught in French or English based on the instructor's preference.

However, *students must have very good ability in speaking, reading, and writing French before applying for this program.* Students will continue to take French at their level while at École Polytechnique.

École Polytechnique has different academic schedules depending on the year of study. Caltech students who study at École Polytechnique for the fall term can only select classes from the third year of the École Polytechnique curriculum, and all classes must be selected from this year's curriculum. Note that the second-year classes are not allowed, as this year goes from the fall through January and then has a second semester versus two terms. The third-year specialized curriculum has a schedule that corresponds closely to Caltech's three-term system, and students must take all classes from the third-year curriculum. These classes are equivalent to 100-level classes at Caltech.

A minimum 3.3 GPA is required to apply. Eligible sophomores and juniors apply to study during their junior or senior year by the Caltech internal deadline, which is usually in January.

Note that students must be nominated by Caltech in order to apply and cannot apply without going through the internal Caltech nomination process, which is run by the Fellowships Advising and Study Abroad Office. Only this office can provide the required nomination. Each year application specifics will be provided to sophomores and juniors in the fall. Students will be required to complete both Caltech Study Abroad Proposal and Forms and complete the École Polytechnique application forms as well as undergoing a formal assessment of French skills by Caltech's French instructor.

Please see the Financial Aid section for details on applying for and eligibility for financial aid related to study abroad. Students who receive financial aid should list supplemental charges and travel in their aid application.

EDINBURGH SCHOLARS PROGRAM

The Caltech Edinburgh Scholars Program offers qualified juniors and seniors the opportunity to spend the fall at the University of Edinburgh. The University of Edinburgh is on a semester system, and Caltech students attend from mid-September to mid-December. All students are required to attend a weeklong orientation held the week before classes start. All students live in university dormitories or flats, which are within walking distance from the George Square (humanities and social sciences) and the King's Buildings (the science and engineering campus). The university operates a free shuttle bus from the George Square campus to the King's Buildings campus.

Students pay Caltech housing, meal plan, tuition, and other standard Caltech fees for the term. There is usually a supplemental charge for housing due to the longer length of the term. The supplement varies yearly depending on prices and the exchange rate.

Students are admitted into one of Edinburgh's academic departments in the College of Science and Engineering (CSE). Note that students cannot be admitted into the economics department because that is in the College of Humanities and Social Sciences, but

they can take 20 credits in that department. Students, whose option is BEM or economics, are allowed to take 40 credits in economics in order to fulfill BEM or economics option requirements if the student also takes 40 credits in the College of Science and Engineering.

Students take a minimum of 60 Edinburgh credits per semester and a maximum of 80 credits, but no more than five courses. Students will take a minimum of two classes in the department is closest to their option and which will serve as the student's admitting department. The two required classes (18 Caltech units) varies from 20 to 40 Edinburgh credits based on whether the two classes are 10 or 20 credit classes each. Students can take all of their classes in their admitting department or can take classes in other CSE departments provided they meet requirements. Students can take 20 credits (one course) in the College of Arts Humanities and Social Sciences or up to two 40 credits in this college if they take 40 credits in the College of Science and Engineering. Note that 60 credits (4 classes) is the standard course load, but most Caltech students take 70 to 80 credits. Note that at least 36 Caltech units must be taken, i.e., 4 classes/60 credits.

A minimum 3.0 GPA is required to apply. Eligible sophomores and juniors should apply by the January deadline for the fall semester at Edinburgh. More information is available about the university at www.ed.ac.uk. Further information, including application procedures and exact deadline dates, is available from the Fellowships Advising and Study Abroad Office: fasa.caltech.edu.

Please see the Financial Aid section for details on applying for and eligibility for financial aid related to study abroad. Students who receive financial aid should list supplemental charges and travel in their aid application.

LONDON SCHOLARS PROGRAM

The Caltech London Scholars Programs offers qualified juniors and seniors the opportunity to spend a fall term at University College London, which is located in the lovely Bloomsbury area of London. University College London (UCL) is on a semester system, and Caltech students attend UCL's autumn semester from about the third week of September to mid-December. All students are required to attend an exchange student orientation the week before the semester begins. Students also attend a new student orientation the first week of the semester. All students live in a UCL dormitory, which is located a short walk or short bus ride from the academic buildings of the UCL campus. Students pay Caltech housing, meal plan, tuition, and other standard Caltech fees for the term. There is a supplemental charge for housing/meals due to the longer length of the term. The supplement varies yearly depending on prices and the exchange rate.

Students are admitted into one of UCL's academic departments in the physical, life, or engineering sciences and must take at least 50% of their classes in their Admitting Department. Usually the Admitting Department is in a subject area that most closely corresponds to the student's Caltech option, but there is some leeway in this provided the student has the background to be admitted to the department in

question in the STEM subjects. Students cannot be admitted into humanities or social science departments.

The remaining 50 percent of classes can either be taken in the Admitting Department, another department in the sciences or engineering, or the humanities and social sciences with the exception of the English literature department, the the Slade School of Design, which do not admit visiting students, even those with majors in English literature or the arts. Note that there are ample opportunities to take literature courses from a number of departments that offer literature classes, e.g., Slavonic and East European studies, Classics, Scandinavian studies, European cultural studies, Hebrew and Jewish studies, French, etc. Note that these departments offer classes taught in translation and in the foreign language.

A typical UCL semester class is 15 UCL credits. Caltech students must take 60 UCL credits during their semester at UCL. This would be equivalent to 36 Caltech units unless a class is equivalent to a 12-unit Caltech class. UCL classes fulfill option credit, humanities or social science credit or general credit. Note that the final number of units and whether the units can be used to fulfill departmental requirements will be determined after faculty review upon a student's return to Caltech.

Students are only allowed to take Year One classes in the economics department. Students can take higher level economics classes in the School of Eastern European and Slavonic Studies.

A minimum 3.3 GPA is required to apply and some departments such as Computer Science (3.9) or the Biological Sciences (3.5) require a higher GPA. Advice on this can be obtained from Caltech's study abroad office.

Certain departments at UCL will not admit fall only exchange student. For this year the subjects include, mathematics, statistical sciences, physics, all engineering sciences except for mechanical engineering, which does admit fall only students.

Eligible sophomores and juniors apply by the January deadline for the fall semester at UCL. Further information, including application procedures and exact deadline dates, is available from the Fellowships Advising and Study Abroad Office www.fasa.caltech.edu/ and further information on UCL is available at: www.ucl.ac.uk.

Please see the Financial Aid section for details on applying for and eligibility for financial aid related to study abroad. Students who receive financial aid should list supplemental charges and travel in their aid application.

MELBOURNE SCHOLARS PROGRAM

The Caltech Melbourne Scholars Programs offers qualified juniors and seniors the opportunity to spend the summer/fall (Semester 2) at the University of Melbourne, which is located in the vibrant city of Melbourne, Australia. Melbourne is on a semester system, and Caltech students attend Melbourne's second semester from the second week of July to the end of November. Since Melbourne is in the Southern Hemisphere, the university's first semester starts in July and crosses over both the Caltech winter and spring terms. Therefore, students attend Melbourne's second semester, which corresponds better to

Caltech's fall semester. All students are required to attend an orientation that takes place at the University of Melbourne the week before the semester begins.

Students live in a residence hall, which is located a short walk from the academic buildings of the campus. Halls of residence have either an apartment or suite setup and offer that vary by hall assigned such as a 15-meter outdoor swimming pool and lounge area, barbecue area, workout gym (with plasma TV, cross trainers, free weights, treadmills, exercise bikes, etc.), café, lounge, computer lab, and laundry. Students share a suite or apartment with other students. Further information on the university is available at www.unimelb.edu.au.

Students pay Caltech housing, meal plan, tuition, and other standard Caltech fees for the term. There is a supplemental charge for housing/board due to the longer length of the Melbourne semester. In some years there could be a supplemental tuition charge. The supplement varies yearly depending on prices and the exchange rate.

Students take four classes at Melbourne. Each class is worth 12.5 Melbourne credit points. Of the four classes, students must take two classes related to their option at Caltech and may take up to two outside of their subject, including the humanities and social sciences. Students are eligible to take one class as a research class in an area related to their option.

The Melbourne credit load would be equivalent to 36 to 45 Caltech units. Melbourne classes can be used to fulfill option credit, humanities or social science credit, or general credit requirements. Note that the final number of units and whether the units can be used to fulfill departmental requirements will be determined after faculty review upon a student's return to Caltech.

A minimum 3.0 GPA is required to apply. Eligible sophomores and juniors apply by the fall deadline for the second semester starting in July. Further information, including application procedures and exact deadline dates, is available from the www.fasa.caltech.edu.

Please see the Financial Aid section for details on applying for and eligibility for financial aid related to study abroad. Students who receive financial aid should list supplemental charges and travel in their aid application.

ROTC

Air Force Reserve Officer Training Corps (AFROTC) offers three- and four-year programs leading to a commission as a second lieutenant in the United States Air Force. The AFROTC program is open to almost all students pursuing baccalaureate degrees. Classes consist of one hour of academics and two hours of leadership laboratory per week for first-year students and sophomores, and three hours of academics and two hours of leadership laboratory per week for juniors and seniors. AFROTC offers a variety of scholarships valued at up to 100 percent of annual tuition, along with a nontaxable monthly stipend. By agreement through the Air Force, Caltech students enroll in Air Force

ROTC classes at the University of Southern California, California State University San Bernardino, Loyola Marymount University, or the University of California, Los Angeles. You do not need to be a student at any of these colleges to attend AFROTC on their campuses. For more information, contact the Department of Aerospace Studies at afrotcdet060@rotc.usc.edu or call (213) 740-2670 or visit usc.edu/afrotc. No military commitment is incurred until entering the junior year of the program or receipt of a scholarship after the first-year student's first year.

The Army ROTC program at USC offers four-, three-, and two-year full-tuition scholarships up to $43,000 a year. In addition, the program pays all contracted cadets a stipend of $3,500 to $5,000 a year and an annual book allowance of another $1,200. High-school students need to apply for the four-year scholarship during the fall of their senior year, and no later than November 15. All Caltech students interested in an Army ROTC three- or two-year on-campus scholarship need to apply early in their spring semester, and no later than March 15, for the next academic year. Completion of the program leads to a commission as a Second Lieutenant in one of 14 occupational branches in the Regular Army, Army Reserve, or the National Guard. These scholarship provisions are subject to change, and interested students are encouraged to contact the Department of Military Science at the University of Southern California for further information: PED 110, Los Angeles, CA 90089, (213) 740-1850.

REGISTRATION REGULATIONS

PROCEDURES

Students must register on the dates specified in the academic calendar. Students are not registered until they have both

- enrolled in an approved list of courses, *and*
- are current with the Bursar's Office. All undergraduate students with an outstanding Bursar's bill balance of $300 or more and graduate students with a Bursar's bill balance of $1,500 or more will have a hold placed on their registration for the subsequent quarter the day before online registration opens. The hold will be released once students have paid their bill in full or worked out a satisfactory payment plan with the Bursar's Office.

Any student who has not completed both parts of registration within one week after the first day of classes will be removed from the Institute rolls.

CHANGES IN REGISTRATION

Students are required to maintain continuity of registration until the requirements for the Bachelor of Science degree are fulfilled, except in the case of an approved undergraduate student leave. All changes in registration must be reported to the Registrar's Office by the student prior to the published deadlines. No credit will be given for a course for which a student has not properly registered. Registration for added courses is complete when a student registers for the course on REGIS or sends a written request to the Registrar's Office with the proper advisor and instructor approvals. A course is considered dropped when a student drops the course in REGIS or notifies the Registrar's Office in writing.

A student may not add a course after Add Day or withdraw from a course after Drop Day, without the approval of the Undergraduate Academic Standards and Honors (UASH) Committee. The responsibility for registering or dropping courses (in REGIS or by direct communication with the Registrar's Office) is on the student. Failure to fulfill the responsibility because of oversight or ignorance is not sufficient grounds to petition for permission to drop or add courses after the deadline. In cases where the late addition of a course would have put the student in a position of overload by Add Day of the term concerned, the student must also obtain an approved retroactive overload from the dean or associate dean of undergraduate students. A grade of F will be given in any course for which a student registers and which they do not either complete satisfactorily or drop.

Humanities Drop Policy

Students who do not attend the first class of the term will be automatically dropped from the class. Students who notify the instructor in advance of their inability to attend the first class may remain enrolled in the class at the instructor's discretion.

Academic Advisement

Students will be assigned first-year advisors, and later option advisors, who will guide students to resources about the curriculum, graduation requirements, and academic policies and procedures. With the guidance of their advisors, students will develop an educational plan for successfully achieving their goals and select courses each quarter to progress toward fulfilling that educational plan. Undergraduate students are required to meet with their advisor at least once a year, but are encouraged to do so more often. Failure to meet at least once prior to the start of spring term will result in a hold placed on the student's record which will prevent them from registering online.

Summer Research or Summer Reading

Qualified undergraduate students who are regular students at the Institute are permitted to engage in research or reading during the summer, but in order to receive academic credit the student must have the approval of their division and must complete the registration process for such summer work before June 1. Any requests to add research after June 1 must be submitted as a Late Add petition to the

Undergraduate Academic Standards and Honors Committee (UASH) as well as be approved by the Division Chair. An undergraduate may not receive payment for research carried out for academic credit. Students who are registered for summer research or reading will not be required to pay tuition for the units. A student may apply up to 18 units of summer research per summer and 36 units in total toward Institute graduation requirements.

UNDERGRADUATE STUDENT LEAVES OF ABSENCE

General Information

Students achieve formal separation from the Institute by filing a completed undergraduate student leave form. A student who leaves the Institute at any time during the term without filing a formal undergraduate leave form will not be considered withdrawn. Any grades reported by instructors will be recorded on the official transcript, and the grade of F will be recorded for all other courses. A student who is absent for a term (or longer), without an approved undergraduate student leave must petition for reinstatement to return to the Institute.

The effective date of a withdrawal is entered by the undergraduate deans. When the withdrawal occurs after Add Day of any term, a W (standing for "withdrawn") will be recorded on the student's transcript for all courses in which the student is enrolled. A grade of W is not included in the computation of the student's grade-point average.

Students on leave **for any reason** are not considered enrolled during the leave period and therefore do not enjoy all the rights and privileges of enrolled students. They also have limited access to Caltech's educational activities, programs, and services. They may not attend classes or labs, live or stay in Institute housing, retain leadership positions, or access certain student resources, including Student Wellness Services or Residential Experience activities or programs during their leave. They also may not obtain employment or do volunteer work on campus. The expectation is that while unenrolled, students are wholly separated from campus. The dean or designee may also require that unenrolled students apply for permission in advance of visiting campus.

When discussing a leave with a dean, a student may request an exception to this general policy, and fill out the “Permission to Participate while on Leave” Form: https://deansoffice.wufoo.com/forms/request-to-participate-while-on-leave/. Failure to gain a dean’s permission to be active on campus or accessing resources inconsistent with those requested in the petition, will be considered when a student on any type of leave applies to return.

Career Achievement, Leadership and Exploration (CALE) is, by default, open to all students who have not been permanently separated from the Institute, regardless of leave or enrollment status, unless otherwise revoked by the Director of CALE or the deans' office.

Students on leave may consult with their advisor and otherwise plan for their academic future; however, they will not receive credit for auditing courses. Students who are on leave are still subject to all

Institute policies, including the Institute Sex- and Gender-Based Misconduct Policy. Violations of policy while on leave may affect a student's eligibility to re-enroll.

Voluntary Leaves

Personal Leaves

A student may request a voluntary leave of absence for personal reasons (personal leave) by submitting a written petition via completion of the undergraduate student leave form. International students should consult with the International Student Programs Office regarding visa implications prior to submitting the leave petition.

The deans may grant a personal leave provided (a) the student is in good standing, in other words does not have to meet special academic or disciplinary requirements as a result of reinstatement, (b) the leave is for one year or less, although special circumstances can be considered for a longer leave, and (c) the leave extends over a period that includes at least one full term. Leaves will not be granted retroactively and must be filed by the last day of classes of the term.

While on personal leave, undergraduate students should not accept employment, start or run a business, or engage in any activity inside or outside of the Institute that creates a conflict of commitment with their full-time, degree-seeking status. To help ensure adherence to this requirement, the Undergraduate Deans' Office may ask students seeking personal leave to disclose all external funding (including fellowships and awards) or employment (part or full time) intended to support any outside activities while on leave.

Students who elect to take a personal leave while involved in pending conduct processes will be expected to participate in the pending conduct process until its completion. However, the Deans' Office may excuse students from participation while on personal leave if extenuating circumstances justify the pause.

A petition to return from a personal leave should be submitted six (6) weeks before the first day of the term for which the student intends to return. Return from a personal leave is subject to the approval of the Deans' Office.

Medical Leaves

If a student is unable to complete their coursework due to medical reasons, the student may petition for a medical leave of absence by submitting a written petition via completion of the undergraduate student leave form. International students should consult with the International Student Programs Office regarding visa implications prior to submitting the medical leave petition.

The duration of a medical leave should be determined primarily by the student's improvement in treatment. In general, however, medical leaves are expected to include at least one full term.

The Institute may impose conditions on return from a medical leave, which may include confirmation from the student's health care provider that the student is following the recommended course of treatment, the student's consent for the provider to discuss the

student's condition or progress during the leave with Caltech officials, including representatives of Student Wellness Services and the Deans' Office, and an independent evaluation of the student's readiness to return by a qualified medical professional. Any conditions of return will be specified at the time of the leave approval.

To request a leave, a student can take the following steps:

1. Submit the leave form.
2. The student should then meet with either:

- The Medical Director of Health Services or designee (for leaves related to medical conditions), or
- The Clinical Director of Counseling Services or designee (for leaves related to emotional, psychological, or psychiatric conditions).

This meeting is to help the student make plans for their treatment during their leave, to discuss the need for any conditions placed on the leave, and to answer any questions the student has about the leave process. After this meeting, the student should give written consent for the Director to communicate their recommendation to the Deans' Office by filling out the release of information and records consent form available on the Student Wellness website.

The Dean or designee may then authorize the medical leave.

It is the expectation that a student on medical leave will focus on managing the condition(s) that precipitated the leave. Any impending or ongoing conduct processes will ordinarily be suspended while a student is on medical leave, unless the student requests otherwise in writing, and their medical provider agrees it is appropriate. However, in some cases, the Title IX Coordinator and/or the Undergraduate Dean or designee may determine that the case cannot be paused.

Return from Medical Leave

This requires the following steps:

1. Submitting a completed Return from Medical Leave form to the deans.
2. Signing a release of information form authorizing any treatment providers to communicate with Caltech, including representatives of Health and Counseling Services to determine the student's readiness to return and recommendations for reasonable accommodations. This form is available on the Student Wellness Services website.
3. Submitting a provider recommendation form to either the Medical Director of Student Health Services or the Clinical Director of Student Counseling Services, or their designee. The student's healthcare provider should fill out this brief form to summarize their work together; to outline any progress the student has made in treatment; and to state any recommendations for returning to the Institute. This form is available on the Student Wellness Services website.

4. After Student Wellness Services has received the provider recommendation form, the student should schedule a meeting with either the Medical Director of Health Services or designee (for leaves related to medical conditions), or the Clinical Director of Counseling Services or designee (for leaves related to emotional, psychological, or psychiatric conditions). In this meeting, the student and the Director will discuss their healthcare provider's recommendations and will discuss the need for any continued treatment. The student should sign a release of information form allowing the Director to communicate a summary of this meeting to the deans. This form is available on the Student Wellness Services website.
5. Final approval of the petition is the responsibility of the dean or designee.

A student returning from a leave for medical reasons will maintain the same academic standing that they had previously - i.e., if on academic probation, the student will remain on probation upon return from leave.

Pregnancy Leave

Consistent with Caltech policy and the requirements of Title IX, students who are unable to complete their coursework or other course of study for a period of time due to a pregnancy, childbirth and related medical conditions are eligible for a medical leave of absence. Students who are pregnant or who have recently given birth are also eligible for reasonable accommodations.

A pregnant student who wishes to take a medical leave should submit a completed after obtaining a recommendation from the Medical Director of Health Services. Medical documentation from the student's treating medical provider is required.

The Institute also provides reasonable accommodations to pregnant students consistent with federal and state law. Reasonable accommodations may include allowing pregnant students to maintain a safe distance from hazardous substances, allowing them to make up tests and assignments that are missed for pregnancy-related reasons or excusing of absences that are medically necessary.

Bonding

An enrolled student in good academic standing who chooses to take a leave of absence because of the birth of his or her child may request a bonding leave by submitting a completed petition form for approval.

Involuntary Leave

The dean or designee may determine that it is necessary to place a student on an involuntary leave in a variety of circumstances, including when a student demonstrates behavior that poses a threat to health or safety, causes significant disruption to the Caltech community, for the personal safety or welfare of the student involved, as an interim measure, or as a result of a disciplinary action.

The dean may impose an involuntary leave in appropriate circumstances, such as where a student's behavior: (1) has, or threatens to, cause significant property damage; (2) significantly disrupts the Caltech community; (3) presents a substantial risk of harm to self or others; (4) indicates the student is unable or unwilling to carry out self-care obligations; or (5) violates a Caltech policy or the honor system. An involuntary leave also may be imposed when that the student requires a level of care from the Institute community that exceeds reasonable accommodations, resources and/or staffing that the Institute can reasonably be expected to provide.

A student placed on any type of involuntary leave is expected to remain away from campus during the duration of the leave. Requests for an exception to this policy should be discussed at the time of the leave decision, and a "Petition to Participate While on Leave" must be approved prior to any such participation. Failure to gain permission, and consequently being active on campus, will be taken into consideration when a student on involuntary leave applies to return.

Review and Decision Process

In making an informed decision to place a student on involuntary leave in such circumstances, the dean will conduct an individualized assessment and consider relevant information including information provided in a timely manner by the student. If the conduct has been the subject of an investigation under an Institute process or procedure, the dean will consider the findings and conclusions reached in that process.

The dean may consult with other Institute personnel, including but not limited to, security and residential life personnel, staff, faculty, and other individuals or departments. If appropriate and feasible, the dean may seek cooperation and involvement of parents or guardians of the student.

Medical information, including medical information provided in a timely manner by the student, may be considered if the behavior is associated with a physical or mental condition. In appropriate cases, the dean may consult with the director of Wellness Services, or designee, and/or require a physical or mental evaluation from a health professional if the dean believes such an evaluation is necessary to make an informed decision. Students are expected, if necessary, to sign a release of information to facilitate discussions between Caltech and the health professional conducting the evaluation. The dean will also consider whether relevant risk factors can be eliminated or reduced to an acceptable level through reasonable accommodation.

Written Decision

The student will be advised in writing of the decision to impose an involuntary leave. The dean may stipulate conditions that must be met before the student may return. An involuntary leave may be a permanent separation from the Institute (i.e. expulsion); for a specific duration or until certain conditions have been met. If the involuntary leave is not a permanent separation, the student will be advised of the length of the leave and/or any conditions for return.

Emergency Leave
If the dean determines that a student's continued presence is likely to pose a substantial risk to the safety and well-being of the student or others, the dean may place the student on an emergency interim leave before a final determination is made. The dean will make reasonable attempts to meet with the student and consider relevant information, including in appropriate cases medical information provided by the student, before deciding on an emergency interim leave. An emergency interim leave will remain in effect until a final decision has been made.

Return from Leave
A student on involuntary leave will not be allowed to return until the dean makes a fact-specific assessment of the circumstances, considers relevant risk factors, and concludes that the student does not pose a significant disruption to the functioning of the Institute community and/or does not pose a substantial risk to the health and safety of the student or others. The dean will consider relevant information, including information provided by the student. In cases where a student has a physical or mental condition associated with the behavior triggering the leave, the dean will also consider whether the relevant risks can be eliminated by a reasonable accommodation. The student will be notified in writing if the dean determines that the student will not be permitted to return from a leave or will be permanently separated from the Institute.

Appeal
A decision by the dean to place a student on involuntary leave may be appealed in writing within ten days to the vice president for student affairs (or designee). If the leave is imposed as a sanction resulting from a finding of responsibility under an Institute process any applicable limitations on grounds for appeal will apply.

Disciplinary Notations on Transcripts
If a student is ineligible to reenroll at Caltech due to the imposition of an involuntary leave, the Institute shall include on the student's transcript a notation stating that the student is ineligible to reenroll at Caltech because they have been subject to a disciplinary suspension or expulsion. A notation of expulsion is permanent, and a notation of suspension will remain on the student's record for seven years.

On request by the student, Caltech may remove from a student's transcript a notation of suspension if:

(1) the student becomes eligible to reenroll at Caltech; **or**

(2) the Institute determines that good cause exists to remove the notation.

SCHOLASTIC REQUIREMENTS

All undergraduates are required to meet certain scholastic standards as outlined subsequently.

ELIGIBILITY TO BE ENROLLED

All undergraduate students must complete a minimum of 27 units per term with a grade-point average of at least 1.9 in order to be eligible to remain enrolled in classes. First-year students are not held to the 1.9 GPA requirement during the first two terms. A student may be excused from the 27-unit eligibility requirement if an underload petition has been approved, prior to Add Day, by the dean or associate dean of undergraduate students. Under exceptional circumstances the deans may waive the requirement that such a petition be approved prior to Add Day, but may do so only once during that student's career at Caltech. In addition, students must earn a total of 108 units per year; this averages to 36 units per term. The 108 unit requirement may be waived in the case of an approved underload by Add Day, terms away, or having been academically ineligible in one of the past three terms.

When a student is ineligible for the first time, students are to send a reinstatement petition to the dean or associate dean of undergraduate students. The dean may choose to reinstate them, in which case they will be on academic probation for their next term of enrollment. Alternatively, the dean may direct them to petition the Undergraduate Academic Standards and Honors Committee (UASH) for reinstatement. UASH will either approve their petition for reinstatement and place them on academic probation, or require them to withdraw from the Institute for at least two terms.

When a student becomes ineligible a second time, they will be required to withdraw from the Institute for at least two terms. Summer does not count as a term. A student who has been required to leave the Institute because of academic ineligibility may, after at least two terms of leave, petition the Undergraduate Academic Standards and Honors (UASH) Committee for reinstatement. The UASH Committee's decision regarding reinstatement will be based largely on whether or not such students have made good use of their time while away from the Institute. Useful activities include being gainfully employed, having an internship, engaging in a significant amount of volunteer work, or successfully completing courses at another college or university. The Committee will also expect that students applying for reinstatement will have completed work in all Caltech classes in which they had received an E or I grade.

When a student becomes ineligible a third time, they will not be allowed to continue to enroll at Caltech.

Process for requesting an exception
Students who are ineligible to petition may request an exception to the above. To do so, they must first obtain permission from two of the following three individuals: the dean of undergraduate students, the chair of the UASH Committee, and the Registrar. Such requests require that a reinstatement petition be sent to the Registrar's Office at least three days prior to the next UASH Committee meeting's published deadline. When sending the reinstatement petition, students are encouraged to include (in the body of the email) an additional note including why the student feels they have an exceptional circumstance that should be considered by UASH outside of the typical reinstatement procedures. If the petition receives sufficient votes, it will be added to the agenda for the following UASH committee meeting.

Students not enrolled due to Academic Ineligibility
Academically ineligible students who are not reinstated will be separated and dropped from any courses for the next academic term. Caltech considers academically ineligible students to be matriculated; however, students not currently enrolled do not enjoy all rights and privileges of enrolled students. Separated students (i.e. unenrolled students), have limited access to Caltech's educational activities, programs, and services. They do not have access to online services including, but not limited to, REGIS and Canvas. They may not attend classes or labs, live in Institute housing, or access certain student resources, including Student Wellness Services, CASS, and Residential Life activities, programs, and services while separated. Career Achievement, Leadership, and Exploration (CALE) is, by default, open to all students who have not been permanently separated from the Institute, regardless of leave or enrollment status, unless otherwise revoked by the Director of CALE or the relevant deans' office. For questions regarding the full scope of these limitations, please contact the relevant deans' office.

Departmental and Option Regulations
By the middle of the third term, first-year students must notify the Registrar's Office of their selection of an option in engineering, humanities, social sciences, or science to be pursued in subsequent years. Upon the selection of an option, a first-year student will be assigned an adviser in that option, whose approval must then be obtained for registration for the following year.

Undergraduate students may request to add an approved minor to their program of study. The request for a minor must be approved by the option representatives of the student's option and proposed minor. A plan must be presented which meets the minimum requirements for both the option and the minor, but the option representatives may impose additional requirements as well. The approved request must be submitted to the registrar before the start of the senior year.

Undergraduate students may be allowed to major in two options for the Bachelor of Science degree. In order to do so the student must

present a rationale for the double option and a plan of study leading to completion of the degree in four years. The plan, and any substantive modifications, must be approved by a committee composed of the option representatives of the two options. The plan must meet the minimum requirements for both options as set forth in this catalog, but the committee may impose additional requirements as well. The approved plan should be submitted to the registrar during the sophomore year, but in any case no later than the start of the senior year. The student will then be assigned an adviser by each option. Consult the registrar for appropriate procedures.

Continuing in an Option
Students whose grade-point averages are less than 1.9 at the end of an academic year in a specific group of subjects designated by their department or option may, at the discretion of their department, be refused permission to continue the work of that option. Such disbarment does not prevent the students from continuing in some other option or from taking additional courses to raise their average in their original option. Students without an option will fall under the direct jurisdiction of the dean of students. Students may remain without an option for no more than one year.

Change of Option
An undergraduate in good standing at the Institute shall be permitted to transfer into any option of their choice provided they have (a) a 1.9 GPA in subjects required for graduation in that option or in a specific group of subjects designated by that option or (b) permission of the option representative or committee. A change of option is effected by obtaining a Change of Option petition from the Registrar's Office. The completed petition must then be signed by the option representative for the new option (who will assign a new adviser), and filed with the Registrar's Office. Institute regulations require that a student who has made normal progress at the Institute be able to change options at any time up to the end of the sophomore year without penalty either as to time until graduation or as to excessive unit requirements in any term.

Term Examinations
Term examinations will be held in all subjects unless the instructor in charge of any subject shall arrange otherwise. No student will be exempt from these examinations. When conflicts exist in a student's schedule, it is the student's responsibility to report the conflict to the instructor in charge of one of the conflicting examinations and make arrangements for another time.

Satisfactory Academic Progress
Eligibility to register is determined by the student's record as of the first day of classes of the term in which registration is sought. A student will be declared ineligible to register if they have completed fewer than 27 units with a 1.9 grade point average in the previous term.

Graduation Requirement
To qualify for graduation a student must complete the prescribed work in one of the options with a passing grade in each required subject and with a grade-point average of 1.9. A grade of F in an elective course need not be made up, provided the student has received passing grades in enough other accepted units to satisfy the minimum total requirements of the option.

A Caltech undergraduate degree is based on four years of academic enrollment (study abroad included) in which students have the time to explore their academic interests in a deep and rigorous way. Students who are admitted as transfer students or 3/2 students may be granted advanced standing and term credit for academic work accepted in transfer to Caltech. However, transfers and 3/2 students must enroll for a minimum of six terms at Caltech. All other regularly admitted students must enroll for four years (12 terms). Any exceptions to the four year requirement must be approved by the dean of undergraduate students and the vice president for student affairs.

Candidacy for the Bachelor's Degree
Students must declare their candidacy for the degree of Bachelor of Science to the registrar on or before the first Monday of November preceding the date on which they expect to receive the degree. All subjects required for graduation, with the exception of those for which the candidate is registered during the last term of their study, must be completed and the grade recorded by the second Monday of May preceding commencement.

Graduation in the Normally Prescribed Time
Any undergraduate student who fails to complete the requirements for graduation at the end of 12 terms must petition the Undergraduate Academic Standards and Honors (UASH) Committee for approval to register for further work each term.

Excess of or Fewer Than Normal Units (Overloads and Underloads)
An overload is defined as registration for more than 48 units for an undergraduate. This limit corresponds to five 9-unit classes plus a 3-unit non-academic class (PE, PVA, SA) or four 9-unit classes plus one 12-unit class. Classroom and laboratory courses are to be limited to 45 units for first-year students for the first two terms and the remaining three units should be used for frontier ("pizza") courses, PE, PVA, SA, or research. Students may take up to 51 units (inclusive) but it requires their adviser's approval for such an overload. To take more units than 51, students will need to petition the undergraduate dean, with the expectation that permission will be granted only in exceptional cases. This policy is aimed at having no effect on currently recommended courses of studies in all options, while putting a very high bar for taking 6 full-time classes simultaneously.

A student who wishes to carry an overload in any term must obtain the approval of their adviser and the dean or associate dean of undergraduate students. Petitions for overloads must be submitted one week before the last day for adding classes in any term.

An underload is registration for fewer than 36 units. Underload petitions for first-year students, sophomores, and juniors must be approved by the adviser and the dean or associate dean of undergraduate students. Seniors may take an underload by presenting for the Registrar's approval a senior underload petition and a course plan for graduation the following June that does not require an overload in any term. Completing fewer than 27 units without prior approval will result in ineligibility; for more information on eligibility, see Scholastic Requirements. Underloads during the first 12 terms will not result in a tuition reduction, only in a reduction in financial aid. After completing 12 terms, tuition will be charged per unit. The dean or disability services coordinator will evaluate exceptions due to medical reasons. For more information about underloads and tuition, see Underloads. For more information about impact to aid, see Underloads and Financial Aid: The Impact of Less than Full-time Enrollment.

ALLOWANCE AND TRANSFER OF CREDIT

Transfer of Credit from Other Institutions
Regularly enrolled students who want to obtain credit for college courses taken elsewhere should obtain the permission of the dean of students and have a copy of the transcript of their work sent to the Registrar's Office. The student should then obtain an Allowance of Credit form from the Registrar's Office and take this, with the transcript as well as any supporting class materials required by the option representative, to the representative of the option in which credit is desired. Pending approval by the option representative, credit will be granted when the Allowance of Credit form, with the appropriate signatures, is returned to the office.

Allowance of Credit in the Humanities and Social Sciences
In general, Caltech students should fulfill Caltech course requirements by taking courses at Caltech. Students are expected to have a well-reasoned educational goal for taking classes elsewhere. The only exceptions are transfer students admitted to advanced standing. Credit for comparable work done at other institutions with similar academic standards is not granted automatically.

Students who wish to take courses elsewhere (whether on leave, in the summer, or during the academic year) should consult, in advance, with the executive officer for the humanities or the executive officer for the social sciences, or their designees, to minimize any misunderstanding regarding the nature of credit they may receive. Upon completion of the course, the student must obtain an Allowance of Credit form from the registrar, obtain the signed approval of the executive officer, or their designee, for transfer credit, and return the completed form to the Registrar's Office. The executive officers are the final authority in the allowance of credit in HSS courses.

Guidelines and specific information about allowance of credit are available from the Division of the Humanities and Social Sciences.

Other Allowances of Credit
Except for transfer credit and credit based on Caltech placement exams upon admission, credit will not be granted for Caltech courses in which the student is not officially enrolled, except in special circumstances by arrangement with the instructor. Such arrangements must be approved by the Curriculum Committee, and the student must petition the Committee before the work is undertaken.

Good Standing and Academic Probation
Good Standing: A student is in good standing if they meet academic eligibility standards and are not currently on any probationary status (either academic or disciplinary).

Academic Probation: Following academic ineligibility (failure to meet minimum academic requirements), when a student is reinstated, they will be placed on academic probation for the term until they successfully complete a term.

UNDERGRADUATE EXPENSES

For first-year and transfer students applying for admission, there is a $75 application fee. This fee is nonrefundable.

Housing contracts must be submitted to the Housing Office by the date specified in the instructions accompanying the contract.

ESTIMATED COST OF ATTENDANCE 2025-26

The chart below lists the estimated nine-month, full-time cost of attendance budgets that are generally applicable to Caltech undergraduate students enrolled in the 2025-26 school year. With the exception of the Orientation Fee, all direct charges, i.e., tuition, fees, housing and food, are divided evenly between the fall, winter and spring terms.

Category	On-Campus	Off-Campus	Living with Parents
Tuition	$65,622	$65,622	$65,622
Fees[1,2]	2,586	2,586	2,586
Housing	12,105	15,219	*See Living Expenses*
Food/Meals	8,886	7,533	*See Living Expenses*
Books, Course Materials, Supplies and Equipment (est.)[3]	1,428	1,428	1,428
Living Expenses	*N/A*	*N/A*	11,835
Personal Expenses (est.)	3,285	5,067	4,140

Total Estimated Cost of Attendance[4]	**$93,912**	**$97,455**	**$85,611**

1. Fees do not include the Caltech Student Health Insurance Plan. Students are not required to purchase health and dental insurance through Caltech provided they have coverage through a comparable plan. The plan will cost for health insurance $5,049 for the 2025-26 school year—$1,683 per Insurance Term and for dental insurance $135 and vision insurance $30.96 for 2025-26 school year, one-time fee in Fall term. Financial aid recipients who enroll in the Caltech Student Health Insurance Plan may request that the expense be added to their estimated cost of attendance by completing the **Financial Aid Request for Caltech Student Health Insurance Plan** form. Students will be offered grant assistance to cover the additional expense.

2. All entering undergraduate students are charged a one-time, $500 Orientation Fee in addition to the mandatory fees applicable to all undergraduate students.

3. A reasonable allowance for the purchase of a personal computer may be added to this estimated cost upon request.

4. A Travel Allowance to (partially) offset the cost of two round trips from a student's primary residence may be added to this estimated cost of attendance **for U.S. Citizens or eligible non-citizens** who reside in the US, associated US territories, Canada, or Mexico.

General Deposit

Each new student is required to pay a general deposit of $100. Upon graduation or withdrawal from the Institute, any remaining balance of the deposit will be applied to the student's outstanding balance or refunded if there is no unpaid balance.

Payment Information

The tuition and fees charge for all students is payable in full before the first day of classes unless the student enrolls in the Transact Payment Plan Option per term. The fee to enroll in the plan is $35.00 per term. You will need to enroll during the Enrollment dates only: Fall Term - 9/11/2025-9/24/2025, Winter Term - 12/11/2025-12/24/2025, and Spring Term 3/11/2026-3/24/2026.

Tuition for the baccalaureate degree is based on four years (12 terms) of academic enrollment regardless of unit load each term or if a student completes graduation requirements a term(s) early. The 12 term academic enrollment requirement is separate from and in addition to any other degree requirements. Official study abroad programs listed in the Catalog fulfill one term of the 12 term requirement.

Since a Caltech degree is based on a four-year enrollment requirement, entering students should expect to be on campus and in person and to be billed tuition for a full four years. Any exceptions must be approved by the dean of undergraduate students and the vice president for student affairs. In addition, aid may not be disbursed to a student to cover full tuition if they are no longer attending classes.

Fees for Late Payment
A $50 late penalty will be charged by the Bursar's Office for failure to clear a past-due account at the beginning of each term.

Fees for Late Registration
Registration is not complete until the student has enrolled in a program approved by their adviser and has paid tuition and other fees. A penalty fee of $50 is assessed for failure to register within five days of the scheduled dates.

Unpaid Bills
All bills owed the Institute must be paid when due. Any student whose bills are past due may be refused registration for the following term. All undergraduate students with an outstanding bursar's bill balance of $300 or more will have a hold placed on their registration for the subsequent term the day before online registration opens. The hold will be released once payment reducing the balance to less than $300 has been cleared by the Institute's bank, which typically occurs 3-5 business days after payment is initiated through Transact/CASHNet. The hold will be released once students have paid their bill at the Bursar's Office. Diplomas will not be released until the bursar account is paid in full.

Caltech ID Card Charges
If an undergraduate student owes more than $300, the student's ID card will be deactivated and they will be unable to charge any new purchases. Cards will be reactivated once students have paid their bill in full at the Bursar's Office.

REFUNDS AND FEES

Refund Policy and Return to Title IV
For all students, the institutional charges, e.g., tuition and housing and food, will be prorated according to the amount of time the student spent in academic attendance before withdrawing from the Institute before the end of the sixth week of the term. These prorated charges will be compared to the payments received on behalf of the student, and the Institute will determine whether the student is entitled to a refund or owes additional funds to Caltech.

For students receiving funds from federal Title IV, from Caltech, and/or from state programs, the Institute will follow federal and other applicable regulations to determine the amount of all program funds the student has earned at the time of withdrawal. In general, the amount of financial aid earned is based on the amount of time the student has spent in academic attendance. If the amount of aid disbursed to the student is greater than the amount the student has earned, unearned funds must be returned. If the amount the student was disbursed is less than the amount the student earned, the student will be eligible to receive a post-withdrawal disbursement.

Post-withdrawal disbursements are required when a student has completed all necessary forms, was enrolled at time of disbursement

or earned more Title IV aid than received. A student is entitled to receive their full aid eligibility based on the earned percentage. The institution has up to 45 days to disburse any grant funding to the student. If a post withdrawal disbursement is identified the student is notified via email by a Financial Aid staff member of their additional aid eligibility. Loans must be offered to the student within 30 days, allowing the student at least 14 days to respond. After 14 calendar days Caltech is not responsible for making any post-withdrawal loan disbursements.

All post-withdrawal disbursements are applied to the student account first, and any resulting credit balance on the student's account must be disbursed as soon as possible and no later than 14 days after the calculation of R2T4.

Determining the Student's Last Date of Attendance or Withdrawal Date

The Registrar's Office is responsible for obtaining requests for withdrawal from the undergraduate or graduate dean and for processing official withdrawals. In order to calculate the refund or repayment, Caltech will establish the student's withdrawal date. This date is one of the following:

- the date that the student began the withdrawal process prescribed by Caltech;
- the date the student otherwise provided notification to the Registrar's Office (written or oral) of their intent to withdraw;
- the midpoint of the academic term if no official notification is provided;
- the date determined by the registrar if there are special circumstances (illness, accident, grievous personal loss); or
- the date the registrar determines the student has not returned from an approved student sabbatical or if the student does not qualify for a sabbatical.

Academically Related Activities that Determine Academic Attendance

The Institute may use the last date of attendance at an academically related activity as the student's withdrawal date. This may occur if a student begins the withdrawal process and then attends an academically related activity after that date. Caltech considers an academically related activity to include the following:

- attendance at a lab
- attendance at a lecture
- completing a quiz and/or test
- participation in a study session
- turning in a class assignment

Activities excluded from being used in determining the last date of attendance include:

- logging in without participation
- academic counseling or advisement session
- participation in housing or meal plans

Determining the Return of Federal Funds
The Financial Aid Office will calculate the federal funds that must be returned to the appropriate federal accounts. If a student withdraws from the Institute prior to the first day of classes for the period of enrollment, Caltech will return 100 percent of the student's federal financial aid in accordance with federal procedures. If a student withdraws any time after the first day of classes for the period of enrollment, the Institute will perform the following:

- Determine the percentage of the payment period that the student completed. If the student completed more than 60 percent of the period, they earned 100 percent of the aid for the period. If the student completed 60 percent or less, the percentage of the period completed is the percentage of aid earned. This percentage is determined by dividing the number of days attended in the period of enrollment by the total days in the period.
- Apply the earned percentage to the amount of aid actually disbursed and the amount that could have been disbursed ("earned aid").
- Subtract earned aid from aid that was actually disbursed. This results in the amount of unearned aid to be returned.
- The Financial Aid Office will allocate the return of funds back to the student aid programs in the following order:

1. Federal Direct Unsubsidized Stafford Loan Program
2. Federal Direct Subsidized Stafford Loan Program
3. Federal Direct PLUS Loan Program
4. Federal Pell Grant Program
5. Federal SEOG Program
6. Other Title IV programs

*Federal Work Study is not included in any of these calculations.

R2T4 Formula Calculation

The following two sample R2T4 worksheets layout all the steps involved to calculate return to title IV aid:

- Sample Worksheet 1: Sample-R2T4.pdf
- Sample Worksheet 2: Sample2-R2T4.pdf

Exceptions for R2T4 calculations:

- Continues to attend at least one Title IV-eligible class
- Did not receive, and is not eligible to receive, any Title IV aid
- Has only received, or is eligible to only receive, Federal Work-Study funds

Special Scenarios for R2T4 calculations

- Student Death: Caltech will perform an R2T4 calculation but will not make any post-withdrawal disbursements to the student's estate.
- Consortium Agreements: The institution that disburses Title IV funds is responsible for performing R2T4 and returning unearned funds.
- Re-entry: A student who re-enters the same program within 180 days retains eligibility for prior aid, including amounts returned under R2T4.

Appeals on Refunds
Any questions or problems related to refunds should be directed to the Bursar's Office. For further information on refunds and repayments, contact the Financial Aid Office, the Graduate Office, or the Bursar's Office.

Underloads
Students who register for less than 36 units ("Underload") will not receive a reduction of tuition. Full tuition will be charged to underloading students' accounts. Also, applicable financial aid will be reduced, in underload situations. For specific information on underload requirements, and special circumstances where an underload may be granted, see Excess of or Fewer Than Normal Units (Overloads and Underloads). Information regarding financial aid and underloads can be found in finaid.caltech.edu/policies/underloads.

For those undergraduate students who are eligible for underloading after completing 12 terms or by approved medical exception (Excess of or Fewer Than Normal Units (Overloads and Underloads), the tuition will be adjusted after Add Day at the AY2025-26 rate of $608 per unit plus $862 for student fees per term. The minimum tuition amount is ten units, a charge of $6,080 per term plus the $862 student fee.

Dropping a Course
Any student who wishes to carry fewer than 36 units in any given term must petition for an underload. Underloads must be approved by the Deans. Underloads for graduating seniors must be approved by the Registrar.

PLEASE NOTE: The Institute will charge students for a minimum of 12 terms of full-time tuition, even if they complete their degree requirements early. Students may NOT receive scholarship assistance for any term in which they are not enrolled at least half-time.

Undergraduate students who underload in a term will have their financial aid, including outside scholarships, adjusted based on the actual number of units students are enrolled in as of Add Day. ***However, the student's Caltech account will be charged full-time tuition.***

Additional information is available in the Financial Aid Office. For more information about impact to aid, see finaid.caltech.edu/policies/underloads

Refund upon Withdrawal
When a student, for whatever reason, withdraws from Caltech during an academic term, a refund of tuition as well as housing and food, if applicable, is calculated. The amount of refund is determined by how much of the term has elapsed. If the student is a recipient of student financial assistance, that assistance, if applicable, will be reduced as a result of their withdrawal. Recent federal legislation determines the amount of refund for recipients of federal Title IV student assistance. It is the purpose of this section to inform students of the financial implications of withdrawal.

If the student is not a recipient of federal financial aid, the Institute's refund policy returns any refund of tuition or housing and food first to the programs from which assistance has been received (i.e., scholarships, Caltech gift assistance). Any amount remaining will then be returned to the student. The non–Title IV portion will be distributed as appropriate, first to outside agencies, as required, then to the Caltech grant, scholarship, or loan, depending on the composition of the aid package. These distributions will occur as credits to the appropriate aid funds and charge(s) to the student's Caltech account.

If the student is the recipient of federal Title IV student assistance, any refund must then be applied first to the federal aid program(s) in the prescribed order listed under Determining the Return of Federal Funds.

In the event that a student's disbursed financial aid exceeds the direct costs on the student's personal account, a credit balance will result. Withdrawal will result in the reversal or repayment of the resulting credit balance.

Honor System Matters
Monies owed to the Institute resulting from a disciplinary decision may be collected through the Bursar's Office, at the request of the dean of students.

Special Fees
Students taking the Summer Field Geology course (Ge 120 ab) should consult with the division about travel and subsistence arrangements and costs.

FINANCIAL AID

Caltech believes that qualified students who wish to attend the Institute should not be prevented from doing so for financial reasons. Although the Institute expects students and families to finance the cost of education to the fullest extent possible, the Institute will make every effort to assist those who need help.

Demonstrated financial need is the difference between the annual cost of attending Caltech and the amount the student and parents can reasonably be expected to contribute toward those costs. Costs include actual tuition, student fees, housing, food/meals, books and supplies, and personal expenses. For U.S. citizens or eligible noncitizens who reside in the United States, Canada, Mexico, or

Guam, costs include a travel allowance designed to (partially) offset the cost (airfare) of two round-trips from a student's home during the academic year. Caltech's estimate of a family's ability to contribute is determined annually in accordance with nationally established guidelines.

Eligibility for each type of assistance varies, depending upon the source of funds. Assistance offered by Caltech includes federal, state, and institutional grants, subsidized part-time jobs, and loans. U.S. citizens or eligible noncitizens (as defined in the Free Application for Federal Student Aid [FAFSA]) may apply for state and federally funded programs. International students may apply for institutionally funded programs.

Applications for admission are evaluated separately from requests for financial aid. Students with complete financial aid applications on file will be considered for all applicable types of need-based assistance. A renewal application must be submitted each year. In addition to direct financial assistance, information is available, upon request, about education payment plans and financial-planning resources. (Learn about non-need-based scholarships and prizes under Prizes and Awards.)

All students who believe they will need assistance to attend Caltech are encouraged to submit a financial aid application. The final day to complete a financial aid application or request a loan is one day after the beginning of the registration period for the term following your last term of enrollment for the year. Please use the table below to determine which deadline applies to you.

Last Term of Enrollment in Academic Year 2025-26	Hard Deadline
Fall Term	**November 21, 2025**
Winter Term	**February 27, 2026**
Spring Term	**May 22, 2026**

The Financial Aid Office staff is happy to talk with students and their families at any time to explain the application process, Caltech's computations, and available programs. For further information on the determination of financial need and on application procedures, as well as on financial aid awards and programs, contact the Financial Aid Office, California Institute of Technology, Mail Code 20-90, Pasadena, CA 91125; call (626) 395-6280; or visit the Caltech Financial Aid Office website at finaid.caltech.edu.

HOW TO APPLY FOR FINANCIAL AID/LOANS

Application Process for Caltech and Federal Financial Aid for Entering Students (U.S. Citizens and Eligible Noncitizens)

Slightly different procedures and deadlines exist for each category of students applying for financial aid. Detailed descriptions of these procedures and priority due dates for prospective and continuing students may be found on the Caltech Financial Aid Office website at finaid.caltech.edu.

Restrictive Early Action

Regular Decision

International Applicants

If you are applying for admission as a first-year student for the fall of 2026 and are not a citizen or permanent resident of the United States at the time of your application for admission, you will need to refer to the Caltech Financial Aid Office website at finaid.caltech.edu/applying/international-students for instructions for applying for financial aid.

Applying for Admissions & Financial Aid

International students who want to apply for financial aid must do so as an incoming first-year. If you do not apply for aid as a first-year, or if you apply but do not qualify for aid as a first-year, you will not be permitted to apply for aid in subsequent years at Caltech. There is no financial aid available for international students who apply for admission as a transfer or 3/2.

If you are applying for aid as an international student, you must disclose that you are planning to apply for financial aid on your admissions application.

Federal Student Aid

International students are not eligible for Federal Student Aid funds. Therefore, they cannot receive the Federal Pell Grant, Federal Supplemental Education Opportunity Grant (FSEOG) or Federal Work-Study, and they cannot apply for additional loan assistance through the Federal Direct Stafford Loan or Federal Direct PLUS Loan programs.

Financial Aid Policies & Application

Aside from the restrictions listed above, financial aid policies are mostly the same for international students as for domestic students, so most of the information on this website is valid for international students as well. However, the financial aid application requirements for international students differ from those of domestic students. Use the links below to find out what documents to submit to apply for aid as an international student.

Application for incoming first-years (Restrictive Early Action)

Application for incoming first-years (Regular Decision)

Application for continuing students

TYPES OF AID AVAILABLE

Financial aid is available to all students to help cover the cost of attending Caltech. There are three main types of aid offered at Caltech:

1. Grants & Scholarships : monetary gifts that are based on demonstrated financial need
2. Work-Study : an allotment of money that needs to be earned each year by working on-campus or at other eligible institutions
3. Loans : borrowed money that will need to be repaid with interest after leaving school

After filling out a financial aid application, undergraduate students will be considered for all three types of aid.

Graduate students are only eligible for loan funding.

CALTECH SCHOLARSHIPS

The majority of financial aid awarded to Caltech undergraduates comes from grants. Grants are considered "gift aid", meaning that they do not have to be repaid or earned. Because of this, grants are the most beneficial form of financial aid.

All scholarships and grants at Caltech are need-based, as the Institute does not have a merit aid program. Undergraduate students who fill out a financial aid application will be automatically considered for scholarships and grants from Caltech and the federal government. Grants are also available from state governments, but the application process varies by state.

Caltech Scholarships are gifts awarded from institutional or endowed funds to help cover the cost of attending Caltech. Unlike loan and work-study funds, there is no standard amount of scholarships you should expect in your package. The award amount depends entirely on your demonstrated financial need. Scholarships can be renewed each year, though the exact amount may change according to your level of need in future years.

Named Scholarships

Some of Caltech's financial aid funds come from gifts that Caltech has received. These funds are awarded as scholarships that are named for their donor. Named scholarships are also need-based, but some have a merit component. If you have sufficient need and meet the specifications for one or more named scholarships, you will be automatically considered for those scholarships.

Any named scholarships you receive will be used to replace a portion of your Caltech Scholarships. If you receive a named scholarship, you may be asked to write a thank-you letter to one or more donors. Many donors are lifelong friends of the Institute, and they appreciate hearing about student life at Caltech today.

FEDERAL GRANTS

Federal Pell Grant
The Federal Pell Grant is considered the "base" of a student's financial aid package. It is the first program for which a student's eligibility is determined.

How to Apply

Students who have filled out the FAFSA will be automatically considered for a Pell Grant.

Eligibility

Pell Grants are awarded to undergraduate students who:

- Have exceptional need
- Have not yet completed a baccalaureate degree
- Are eligible for federal student aid (most domestic students)

Award Amount

Up to $7,395, though the amount awarded will vary based on the student's calculated family contribution and enrollment status. Students may only receive Pell Grant for up to 18 quarters (six years).

Federal Supplemental Educational Opportunity Grant (FSEOG)
The FSEOG program is an additional federal grant program. FSEOG funds are first awarded to students with exceptional financial need, with priority given to Pell Grant recipients.

How to Apply

Students who have filled out the FAFSA will be automatically considered for an FSEOG.

Eligibility

FSEOGs are awarded to undergraduate students who:

- Have exceptional need
- Have not yet completed a baccalaureate degree
- Are eligible for federal student aid (most domestic students)

Award Amount

Up to $4,000

STATE GRANTS

Cal Grant A
Provides tuition and fee assistance to undergraduate California residents seeking their first bachelor's degree. Awarded on the basis of cumulative grade-point average and financial need. Qualifying students can receive up to $9,358, renewable for up to four years. Continuing Cal Grant recipients must maintain good academic standing in addition to financial need. They are not required to resubmit verification of their grade-point average for renewal.

More information about Cal Grants is available through the Cal Grant website.

How to Apply

To apply for a Cal Grant, California residents must:

- File a FAFSA
- Return the Cal Grant GPA Verification Form to CSAC.

The deadline to apply for a Cal Grant is March 2nd. You can manage your Cal Grant account online by using WebGrants 4 Students.

Cal Grant B
Provides a living-allowance stipend and tuition/fee assistance to undergraduate California residents seeking their first bachelor's degree. Awards are based on cumulative grade-point average and high financial need. Recipients are generally from disadvantaged economic or educational backgrounds. Awards for first-year students provide up to $1,648 for books and living expenses. When renewed or applied beyond the first year, awards may also include tuition and fee assistance of up to $9,358. Continuing Cal Grant recipients must maintain good academic standing in addition to financial need. They are not required to resubmit verification of their grade-point averages for renewal.

More information about Cal Grants is available through the Cal Grant website.

How to Apply

To apply for a Cal Grant, California residents must:

- File a FAFSA
- Return the Cal Grant GPA Verification Form to CSAC.

The deadline to apply for a Cal Grant is March 2nd. You can manage your Cal Grant account online by using WebGrants 4 Students.

EDUCATIONAL LOANS

Loans can be an invaluable resource for financing an education. While loans are a type of financial aid, they are not a gift like grants and scholarships, since loans need to be repaid eventually. Loans are mostly a tool for liquidity management: they allow you to postpone paying for a portion of your education. See borrowing statistics at Caltech.

All financial aid applicants are considered for a need-based loan from the Caltech Loan programs. If you need additional funding, more federal loans are available through the Federal Stafford Loan and Federal PLUS Loan programs. You may also choose to search for loans on the private lending market.

Disclosure

- Federal Student Loans are required by law to provide a range of flexible repayment options, including but not limited to, extended repayment and income contingent repayment plans, and loan forgiveness benefits which other student loans are not required to

do.

- Federal loans are available to students regardless of income.

The Federal Direct Loan Program

This program offers eligible students and parents the opportunity to borrow money directly from the federal government to help pay the cost of attendance at Caltech. The U.S. Department of Education makes loans, through Caltech, directly to students and/or parents. The Institute will use the loan(s) to pay your tuition/fees and other direct charges such as housing and food/meals, and give the student any remaining money for indirect costs. Students and/or parents make their repayments directly to the federal government.

Direct loans include

1. The Federal Direct Stafford Loan Program;
2. The Federal Direct Parent PLUS Loan Program; and
3. The Federal Direct Consolidation Loan Program.

Federal Direct Stafford Loan

There are two types of Federal Direct Stafford Loans: subsidized and unsubsidized. The federal government pays the interest on subsidized loans while the borrower is enrolled at least half-time and during authorized periods of deferment. The interest on unsubsidized loans begins to accrue immediately upon disbursement and is generally capitalized (added to the amount borrowed) when the borrower is no longer enrolled at least half-time.

Eligibility for Direct Subsidized Stafford Loans is based on financial need as demonstrated by the FAFSA. Students who do not demonstrate sufficient need or whose need is met may borrow Direct Unsubsidized Stafford Loans provided their total financial aid, including the Stafford Loan, does not exceed the total estimated cost of attendance.

Dependent undergraduate students (excluding students whose parents cannot borrow Parent PLUS loans) may borrow Stafford Loan amounts not to exceed an annual total.

Borrowing Limit

Undergraduates: The annual borrowing limit varies based on a student's year in school and dependency status.

Dependent Students

Dependent Student Borrowing Eligibility

Year in Schoool	Total Eligibility	Maximum Subsidized
1st Year	$5,500	$3,500
2nd Year	$6,500	$4,500
3rd & 4th Year	$7,500	$5,500
Aggregate	$31,000	$23,000

Independent Students
Independent students Borrowing Eligibility

Year in School	Total Eligibility	Maximum Subsidized
1st Year	$9,500	$3,500
2nd Year	$10,500	$4,500
3rd & 4th Year	$12,500	$5,500
Aggregate	$57,500	$23,000

Graduates: $20,500 in Unsubsidized Stafford Loans per year, up to $138,500 total. The aggregate limit includes all Stafford Loans received for undergraduate study, and can be made up of no more than $65,500 in Subsidized Stafford Loans.

Stafford Loan interest rates
The interest rates on Stafford loans are now linked to the yield on the 10-year Treasury Note. This means that economic factors will determine the interest rates for loans borrowed in any given year. The interest rates on these loans are fixed and will not change after the loan has been disbursed. The table below shows the current interest rate, along with rates from the recent past.

Undergraduate students:

Enrollment Periods Beginning Between	Interest Rates	
	Subsidized	Unsubsidized
July 1, 2025 - June 30, 2026	6.39%	6.39%
July 1, 2024 - June 30, 2026	6.53%	6.53%
July 1, 2023 - June 30, 2024	5.50%	5.50%
July 1, 2022 - June 30, 2023	4.99%	4.99%
July 1, 2021 - June 30, 2022	3.73%	3.73%
July 1, 2020 - June 30, 2021	2.75%	2.75%

Graduate students:

Enrollment Periods Beginning Between	Interest Rates
	Unsubsidized
July 1, 2025 - June 30, 2026	7.94%
July 1, 2024 – June 30, 2025	8.08%

July 1, 2023 – June 30, 2024	7.05%
July 1, 2022 – June 30, 2023	6.54%
July 1, 2021 – June 30, 2022	5.28%
July 1, 2020 – June 30, 2021	4.30%

Stafford loans are also subject to a loan fee, which is a percentage of the loan amount. Loans are assigned a fee percentage based on the date their first disbursement is made.

First Disbursement Made	Loan Fee
October 1, 2020 – September 30, 2026	1.057%
October 1, 2019 – September 30, 2020	1.059%
October 1, 2018 – September 30, 2019	1.062%

The maximum repayment period under this program is 10 years, not including authorized periods of deferment. Direct Stafford Loans have a six-month grace period that starts the day after the borrower graduates, leaves school, or drops below half-time enrollment. Repayment begins when the grace period ends. Deferments are available for new borrowers during at least half-time enrollment at an eligible institution; during periods of academic study in approved graduate fellowship or rehabilitation programs; and for periods of unemployment and economic hardship.

Applications for Federal Direct Stafford Loans are available on the Caltech Financial Aid Office website finaid.caltech.edu/typesofaid/loans/stafford. Complete information on Stafford Loan deferments and repayment options is also available from the Financial Aid Office.

FEDERAL PARENT PLUS LOAN

Federal PLUS loans are available to the parents or stepparents of dependent undergraduate students as well as graduate students. These credit-based loans require the student to be eligible for Federal Student Aid (most domestic students), and students must file a FAFSA in order to qualify for a PLUS loan.

	Interest Rates
Enrollment Periods Beginning Between	Unsubsidized
July 1, 2025 - June 30, 2026	8.94%
July 1, 2024 – June 30, 2025	9.08%
July 1, 2023 – June 30, 2024	8.05%
July 1, 2022 – June 30, 2023	7.54%

July 1, 2021 – June 30, 2022	6.28%
July 1, 2020 – June 30, 2021	5.30%

Interest is charged on Direct Parent PLUS loans during all periods, beginning on the date of the loan's first disbursement. There is no annual limit to the amount that can be borrowed through the Parent PLUS loan program. In general, parents may borrow the difference between the cost of the student's education and any other financial aid received. PLUS loans may also be used to pay for all or part of the expected family contribution. In addition to the interest, parents pay a loan fee.

First Disbursement Made	Loan Fee
October 1, 2020 – September 30, 2026	4.228%
October 1, 2019 – September 30, 2020	4.236%
October 1, 2018 – September 30, 2019	4.248%

Federal Direct Parent PLUS Loans will enter repayment 60 days after the loan is fully disbursed. Parents may request a deferment from their loan servicer while their student is enrolled in school at least half-time and up to six months afterwards. Once the deferment is over, the loan will need to be repaid.

Graduate Students

PLUS Loans will be placed into deferment until six months after a student stops attending school at least half-time. Once the deferment is over, the loan will need to be repaid.

Applications for Federal Direct PLUS loans are available on the Caltech Financial Aid Office website finaid.caltech.edu/typesofaid/loans/plus. Applications must be submitted to the Financial Aid Office for eligibility certification.

Federal Student Aid Ombudsman

The Federal Student Aid Ombudsman works with student loan borrowers to informally resolve loan disputes and problems. The office of the ombudsman helps borrowers having problems with the following federal loans: direct loans (subsidized and unsubsidized Direct Stafford Loans, Direct PLUS loans, and Direct Consolidation Loans); Federal Family Education Loans (subsidized and unsubsidized Stafford Loans, FFEL PLUS loans, and FFEL Consolidation Loans); guaranteed student loans, SLS loans, and Federal Perkins Loans. If a student needs the assistance of the ombudsman in order to resolve disputes or problems, they may contact the office at U.S. Department of Education at studentaid.gov/feedback-ombudsman/disputes/prepare to submit a complaint.

Caltech Loans
Generally, no interest is charged and no repayment of principal is required while a student maintains a continuous course of study at Caltech. Repayment on Caltech loans begins nine months after graduation, leaving school, or less than half-time enrollment. Caltech loans may carry up to an annual interest rate of 5%. More specific information is provided on the promissory note and the disclosure statement provided to students prior to disbursement of the loan.

Other loans/emergency loans may be available to students regardless of their eligibility for financial aid. These loans are usually payable within the same academic year and are administered by the dean of students on a case-by-case basis. Additional information and applications may be obtained from the dean of students' office deans.caltech.edu/Grants_Funding/short-term-and-emergency-resources.

The Dean's Office also has a no-interest, 30-day emergency-loan program for students who need funds on a short time basis. The loans are ordinarily limited to $500 but there is some flexibility with regard to this limit. Additional information and applications may be obtained from the Dean's Office deans.caltech.edu/Grants_Funding/short-term-and-emergency-resources.

Private Loans
A private education loan is a student loan issued by a private financial institution https://www.finaid.caltech.edu/typesofaid/loans/private. Since they are not originated by the Department of Education, private loans will not be subsidized by the federal government. Additionally, private loans will not have the same features as their federal counterparts, so interest rates and repayment options will vary.

If you are considering a private education loan, make sure you:

- Look for ways to reduce your expenses before you decide how much to borrow.
- Borrow only what you absolutely need.
- Ask questions and compare the rates and terms offered by different lenders.

Note: The amount of your private loan will be disbursed in three equal payments, one per term.

Helpful link to find a private education loan: finaid.org

STUDENT EMPLOYMENT

Work programs provide students with the opportunity to earn money to help with college expenses while gaining valuable job experience. Student employment opportunities are generally available to all Caltech students, even those who have not applied for financial aid or qualified for need-based aid. On campus employers are encouraged to post opportunities through the Career Achievement, Leadership, and Exploration platform.

Students typically work an average of 4-10 hours per week. Please note that students may work a maximum of 16 hours per week (no more than 12 hours per week as undergraduate teaching assistants).

Undergraduate TAs must be in good academic standing (eligible, and not on probation), and good disciplinary standing (not on disciplinary probation) for the term in which they are serving as a TA, and must be approved by the undergraduate deans. Students can expect to earn at least the City of Pasadena minimum wage of $18.04 per hour. Compensation rates will vary based on the position, a student's skills, and previous work experience.

Additional policies and procedures for teaching assistants, including undergraduates with teaching responsibilities maybe be found in the graduate students' information section found in the Center for Teaching, Learning, & Outreach (CTLO) ctlo.caltech.edu/universityteaching/programs/training/ta-orientation.

Federal Work-Study

Work-Study is a financial aid program that allows students to earn money for their college expenses through work. Students who participate in the Work-Study program also gain valuable job experience.

Awarded to domestic students who have demonstrated exceptional financial need through their submission of the FAFSA, this federally funded program provides part-time employment to eligible students. Students are typically awarded $2,500 in Federal Work-Study (FWS).

Please go to the work-study page on the Caltech Financial Aid Office website finaid.caltech.edu/typesofaidworkstudy for additional information about student employment at Caltech.

Hard Deadlines

The hard deadline is the final date to complete a financial aid application, request a change to your financial aid award, or apply for a loan. We cannot accept any documents or requests after the hard deadline has passed. There are no exceptions to the hard deadline.

The deadline is one day after the beginning of the registration period for the term following your last term of enrollment. Please use the table below to determine which deadline applies to you.

Last Term of Enrollment in Academic Year 2025-26	Hard Deadline
Fall Term	**November 21, 2025**
Winter Term	**February 27, 2026**
Spring Term	**May 22, 2026**

Example 1: You attended during fall and winter terms but are not enrolled during spring. You would use the winter deadline.

Example 2: You attend during fall term but take winter term off; you end up returning during spring term. You would use the spring deadline.

Caltech Work-Study

The Caltech Work-Study is designed to parallel the Federal Work-Study program, making Work-Study funds available to students who do not qualify for federal financial aid (including most international students). There are a few differences between the two programs, though. Students who receive Caltech Work-Study may only earn money by working for Caltech.

Wages earned under the Caltech Work-Study program are subsidized by Caltech's financial aid fund. The fund will pay 60% of a student's wages, leaving the hiring department to pay the remaining 40%.

FINANCIAL AID WHEN STUDYING ABROAD/AWAY

Caltech provides student financial aid (in the form of grants, scholarships, and loans) to those undergraduates with demonstrated financial need who desire to participate in the Institute-sponsored University of Chicago Study Away Program, Caltech Cambridge Scholars Program, Caltech Copenhagen Scholars Program, Caltech Edinburgh Scholars Program, École Polytechnique Scholars Program, Caltech London Scholars Program, or Melbourne Scholars Program. Enrollment in a study-abroad program approved for credit by Caltech will be considered enrollment at the Institute, for the purpose of applying for and receiving federal student financial assistance. To be eligible for consideration in Caltech's study-abroad programs, students must be in good academic standing, as defined in the *Caltech Catalog* and as certified by the Institute's registrar. They must also meet the minimum GPA requirement as outlined in the information provided by the Fellowships Advising and Study Abroad Office. In addition, students selected to be Cambridge, Copenhagen, École Polytechnique, Melbourne, or University College London scholars will be provided a memo of understanding outlining the terms of their study-abroad participation. (Check out Study Abroad.)

Costs include but are not limited to tuition, fees, housing, food/meals, additional meals not covered by a board contract, books, supplies, personal expenses, and a standard transportation allowance from the student's home to Caltech. Transportation expenses related to the student's travel between Caltech and the study-abroad institution are the responsibility of the student; financial aid recipients may be offered low interest Institute loans to cover study-abroad travel expenses. Students will have their expected family contribution and financial package calculated in the same manner as other students. Students studying abroad are subject to the standard Caltech policy of a maximum of 12 terms of eligibility for financial aid. University of Chicago Study Away Program, Cambridge, Copenhagen, University College London, École Polytechnique, University of Edinburgh, and Melbourne University candidates must meet all financial aid priority deadlines and eligibility requirements to receive aid. It is the student's responsibility to ensure that all necessary documents are filed and complete with regard to their application for financial aid. University of Chicago Study Away Program participants and Cambridge, Copenhagen, University College London, École Polytechnique,

University of Edinburgh, and University of Melbourne Scholars will continue to be considered for available federal, state, Caltech grant, scholarship, and loan funds. The Fellowships Advising and Study Abroad Office will make the necessary arrangements with the Bursar's Office to ensure that scholars who may be eligible for funds in excess of the direct charges to the Institute receive those funds prior to their departure.

OTHER RESOURCES

Outside scholarships are funds awarded by private organizations, companies, foundations, or community groups, not directly affiliated with the government or the student's chosen college or university. These scholarships can be a significant help in financing higher education, as they do not need to be repaid like loans. If you are interested in applying for outside scholarships, you can find scholarship opportunities by using a scholarship search website. A few options include:

- Fastweb
- College Board BigFuture
- Nitro by Sallie Mae
- College Scholarships.org

How Outside Scholarships/Resources, Tuition Benefits and Tuition Reimbursements Are Treated

Outside Scholarship & Resource Reporting Form

You may be awarded Work-Study and loans as part of your financial aid package. These types of financial aid are considered "self-help" aid, as they need to be earned or repaid, respectively. Any outside resources you receive will be used to replace your Work-Study and loan funds. This will reduce (or even eliminate) the amount of money you will need to earn in school or repay afterwards. Awards will be replaced by scholarship funds in the following order:

1. Work-Study
2. Caltech Loan

If you are receiving need-based financial aid from Caltech, *outside resources cannot be used to reduce your family's expected contribution.* Your total financial aid, including outside resources, cannot exceed your demonstrated financial need. Any outside funds that remain after replacing all of the awards listed above will be used to offset a portion of your Caltech Scholarship.

Because of these restrictions, adding an outside resource to your package cannot increase the quantity of funds available to you. Outside scholarships/resources can only improve the quality of your package by replacing your self-help aid with gift aid.

The full amount of any outside scholarships/resources received will be allocated to your financial aid for the academic year in which it was received. Caltech Financial Aid cannot process outside scholarships/resources across multiple academic years.

Arrangements for multi-year scholarships/resources must be made with the awarding organization.

FINANCIAL AID DISBURSEMENT

Most financial aid funds are credited directly to your student account and are applied first to institutional charges for the current term. Funds are credited no earlier than 10 days prior to the first day of the term. Aid that can be credited directly to your account will be credited when you have accepted or declined your awards on access.caltech;

- provided all required documents for the aid programs you have been awarded
- made satisfactory academic progress;
- enrolled in at least the minimum number of credits for the financial aid programs you have been awarded;
- completed all necessary loan documents and, for first-time Direct Stafford Loan borrowers, completed the online Entrance Interview.

If the disbursement of aid results in a credit balance, any aid awarded in excess of institutional charges will be paid to the student as a refund. Refunds must be requested by the account holder. Requests may be made by e-mail or in person at the Bursar's Office. Prior to receiving funds, you will need to complete the Bursar's Account Refund Form located here. Refunds can be obtained by ACH direct deposit or by check. Refund checks are requested by the Bursar's Office and issued by Accounts Payable and usually take 2-3 weeks to receive in the mail from the day of request.

Outside scholarships are usually disbursed in the form of a check and must be handled according to the sponsor's specifications. If the funds are sent to the Financial Aid Office or the Bursar's Office, they will be credited to your account. Again, if the crediting of any outside scholarship results in a credit balance on your account, you may request that the credit balance be refunded to you. Federal regulations allow Caltech to credit financial aid funds to your account for payment of tuition, fees, housing and food/meals charges. You must give the Bursar's Office written authorization to keep a credit balance on your account from one term to the next term during the academic year. Federal guidelines prohibit keeping a credit balance from one academic year to the next. If you complete your financial aid file late in the term, resulting in the late disbursement of your financial aid funds, you may be subject to late fees assessed by the Bursar's Office.

Cal Grant B stipend payments will be credited to your tuition account unless you contact the Financial Aid Office in person within the first three weeks of the term to make alternate arrangements. Again, if the crediting of any financial aid results in a credit balance on your account, you may request that the credit balance be refunded to you.

In general, loans are disbursed in three installments, one at the beginning each term. For most Caltech students who are enrolled for the full academic year, this means that one-third of their loan(s) will be

disbursed at the beginning of the fall term, another at the beginning of the winter term, and the final third at the beginning of the spring term. Stafford Loans are prorated for undergraduate students if their final period of study is less than a full academic year, such as attending only one term and graduating. Proration ensures the student receives the correct portion of their annual loan limit for the shorter enrollment period, as they will not be enrolled for the full academic year.

If you work through either the Federal Work-Study or the Caltech Work-Study program, you will be paid by check through the biweekly Caltech payroll system. Checks are normally distributed at your actual work site.

Since financial aid is generally awarded on the assumption of full-time enrollment, it is possible that some or all of your aid will need to be adjusted if your enrollment status results in a reduction in your tuition for a term. If you withdraw or drop below half-time enrollment after the last day for adding classes for a term, you may be required to repay all or a portion of the aid that has already been credited to your account. You must inform the Financial Aid Office if you take a leave of absence or change your enrollment subsequent to receiving your financial aid. Cal Grant recipients who take a leave of absence are advised to contact the California Student Aid Commission (csac.ca.gov) and submit a form to remain eligible for the program.

You have the right to cancel your loan(s) any time before disbursement and up to 14 days after disbursement.

SATISFACTORY ACADEMIC PROGRESS (SAP)

34 CFR 668.34

To remain eligible for financial aid, a student must maintain Satisfactory Academic Progress (SAP) and must be in good academic standing as defined by the policies outlined in the Scholastic Requirements section below. The Satisfactory Academic Progress (SAP) regulations require that a student make qualitative (grade-based) and quantitative (pace) progress toward their degree each academic year. The qualitative (grade-based) requirement is measured by a cumulative GPA. The quantitative (pace) requirement is the pace at which you progress toward your degree and earn units. Students must also not exceed the maximum timeframe of attendance. The Satisfactory Academic Progress policy requires students to complete a certain number of units and maintain a certain grade point average after each academic year. The institution does not consider a student's paying for classes on their own or sitting out for an enrollment period as sufficient to re-establish eligibility for Title IV aid.

Satisfactory Academic Progress Requirements

Frequency of Monitoring and Evaluation

34 CFR 668.34(d)

Federal and state regulations governing student financial aid programs require the Institute to ensure that each student who is receiving financial aid maintains Satisfactory Academic Progress (SAP) toward their degree.

The SAP check occurs annually after grades are posted at the end of the academic year. Failure to meet the standards of satisfactory academic progress may disqualify a student from enrollment at the Institute and/or additional federal, state, and institutional financial aid. A student who successfully appeals their ineligibility for registration will be placed on probation or continued on probation status for financial aid purposes.

Financial Aid Probation
34 CFR 668.34(d)(2)

Students who are found not to be making satisfactory academic progress at the end of the academic year will be ineligible to register. For the first such ineligibility, the reinstatement petition may be acted on by the dean or associate dean of undergraduate students, after consultation with the student and examination of the record. At the dean's discretion, such cases may be referred to the UASH Committee for action. If given permission to register, students will be on academic and financial aid probation. A student may continue to receive financial aid while on financial aid probation. Students should use this opportunity to re-establish SAP.

Students who fail to make satisfactory academic progress at the end of the academic year will be ineligible to register and ineligible for financial aid. Students may appeal this status as outlined in the Scholastic Requirements.

Continued on Financial Aid Probation
34 CFR 668.34(d)(3)

Students who fail to make satisfactory academic progress while on financial aid probation for one academic year but are reinstated as a result of a UASH petition, will be continued on financial aid probation and be ineligible for federal and state aid. A student may be continued on financial aid probation for one academic year.

Financial Aid Suspension
Students who fail to make satisfactory academic progress after being continued on financial aid probation for one academic year and are again reinstated by the UASH Committee will be ineligible for federal, state, and institutional financial aid at Caltech until such time as they make satisfactory academic progress.

Students may appeal the financial aid suspension to receive institutional aid.

Appealing Financial Aid Suspension
To appeal your Financial Aid suspension, please complete this form: SAP Appeal Request

If the appeal is denied, students may request a second review from the Vice President of Student Affairs (VPSA). The VPSA's decision is final and cannot be appealed.

Scholastic Requirements
All undergraduates are required to meet certain scholastic standards as outlined below.

Qualitative standard
34 CFR 668.34(a)(4)(i)

GPA: Cumulative GPA of at least 1.9.

Caltech includes all courses taken towards the student's program of study regardless of any institutional academic amnesty or renewal policy when reviewing SAP. Students cannot have their lowest grade excluded or retake a passed course to try for a higher grade.

Quantitative Standard and Pace
34 CFR 668.34(a)(5)(ii)

Units per year: Students must earn a total of 108 units per year; this averages to 36 units per term. All students must complete at least 27 units per term.

Maximum Timeframe
34 CFR 668.34(b)

A student has a limited time frame to complete all degree requirements and remain eligible for financial aid. As defined by federal regulations, the maximum time frame is 150 percent of the published program length for degree completion.

To qualify for a Bachelor of Science degree, students must complete a minimum of 486 units which translates to 486 x 150% = 729 maximum attempted units.

An "attempted" unit is defined as any unit that a student remains enrolled in AFTER the Add Period, including units the student withdraws from each term. Units that a student is retroactively enrolled in after the Add Period are considered attempted units.

https://catalog.caltech.edu/current/information-for-undergraduate-students/scholastic-requirements/

UASH flowchart for determining academic ineligibility and options for continued enrollment.

Grades and Grading
All permanent grades recorded for first-year students in Core classes during the first and second terms they are enrolled will be either P, indicating "passed," or F, indicating "failed." The temporary grade of I ("incomplete") may be used as it is for other students. The temporary grade of E may be given to first-year students as described below for other students. It may also be used in a continuing course if the performance of the first-year student concerned is not significantly below the current passing level, and if the student is maintaining a steady and substantial improvement; an E given for this reason will be automatically changed to an appropriate grade if the first-year student earns the grade for the following term, and will change to an F if the student receives an F for the following term. The grade may not be used in this way for two successive terms nor for the last term of the course.

If a first-quarter or second-quarter First-Year student is enrolled in a course from the list of introductory courses below and the instructor for that course gives letter grades, then the registrar will record P for all passing grades. No grades given to a First-Year student for such a class during the first and second quarter in which they are enrolled will be used in computing the cumulative grade-point average. Computation of grade-point averages begins at the end of the third term of the first year; the cumulative grade-point average will include any letters grades received for non-Core non-introductory classes taken for letter grades during the first two terms of the first year.

The list of introductory courses to which this policy applies is:

- Bi 8
- Ma 2
- Ma 3
- Ph 2ab
- Ph 12ab
- Ch 41ab

Classes that are not part of the Core curriculum or the list of introductory classes above, even if taken in the first two quarters of the first year, can only count towards fulfilling graduation requirements if their grading scheme meets the requirement of the particular option.

First-quarter and second-quarter First-Year students receive pass/fail grades in all Core and introductory courses listed by virtue of their classification as First-Year students by an admissions committee or, for students whose status after the first year is uncertain, by the Undergraduate Academic Standards and Honors Committee.

For all students beyond the first and second quarters of their first year (as a first-year student), graduate and undergraduate, letter grades will ordinarily be used to indicate the character of the student's work: A, excellent; B, good; C, satisfactory; D, poor; E, conditional; F, failed; I, incomplete. P may also be used as described below under Pass/Fail Grading. In addition, grades of A+ and A–, B+ and B–, C+ and C–, and D+ may be used. In any situation in which no grade is reported, the grade shall be assumed to be F.

https://catalog.caltech.edu/current/general-information/grades-and-grading/

E and I Grades

E Grades. At their discretion, instructors may give students who have not completed their work for a course by the end of the term a grade of E. The grade E indicates deficiencies that may be made up without repeating the course. If the instructor does not specify a date on the grade report sheet for completion of the work, students receiving an E will have until Add Day of the following term to complete their work for that course. Instructors may, however, require the work for the course to be completed by an earlier date. In addition, students should be aware that E grades can impact ability to meet eligibility requirements. If an E grade impacts a student's academic standing, the grade may be due by the first day of classes. See section Scholastic

Requirements for additional information.

If a student receives an E and does not complete the work by the date specified by the instructor or by Add Day (or a different date specified by the instructor), the grade will be changed to an F. Adequate time must be afforded to instructors to grade the work and to submit the final grade to the registrar.

It is the responsibility of a student receiving an E to confirm that the registrar has recorded the terms for satisfying the completion of the work in the course.

With the written permission of the instructor, a student may extend the E grade past Add Day of the following term, but doing so will cause an additional E grade to be registered. Each additional extension of the E will be until the date specified by the instructor or until Add Day of the following term, but in each case will require the written permission of the instructor and the registering of an additional E grade.

E Count Limitations. After an undergraduate student has been awarded the grade of E six times, they are not eligible to receive E grades in any subsequent term. A petition for an E in a subsequent term may be approved by the Undergraduate Academic Standards and Honors (UASH) Committee in an exceptional case. Such a petition requires the support of the instructor and the dean or associate dean of undergraduate students.

I Grades. The grade I is given only in case of unexpected sickness or other emergency, occuring near the end of the term, that impedes the completion of the work in the class. An I grade is not intended to allow students to make up missed work from the majority of the term. If a student has not completed the majority of the work, they are not eligible for an incomplete and they will be advised to late drop the class or take a leave. It is given at the discretion of the instructor, after approval by the dean or associate dean of students or the dean of graduate studies. If a student is seeking an I grade due to a severe exacerbation or onset of a disability that occurred near the end of the term, they should contact Caltech Accessibility Services for Students (CASS) at cass@caltech.edu.

The time period within which the grade of I is to be made up should be indicated on the grade sheet, or students receiving an I will have until Add Day of the following term to complete their work for the course. In addition, students should be aware that I grades can impact ability to meet eligibility requirements. If an I grade impacts a student's academic standing, the grade may be due by the first day of classes. See section Scholastic Requirements for additional information.

Students receiving grades of E or I should consult with their instructors, and one of the deans, at the time of issue regarding the work required and the time allowed. This time should, in most cases, coincide with the date fixed in the calendar for removal of conditions and incompletes (Add Day), and in fact if no other time is specified, this date will be assumed. However, except under extraordinary circumstances, the time for the completion of the work will not be extended beyond one year after the date in which the grade of E or I was given. In the absence of an earlier deadline, an E will turn into an F

one year after the date on which the E was given, and an I grade will turn into a W (standing for "withdrawn") one year after the date on which the I grade was given. For undergraduates, waiving of this one-year rule is done in only the most exceptional of circumstances and requires the agreement, before that one year anniversary, of the Dean of Undergraduate Students, chair of UASH, and executive officer of the department in which the course was taken. For graduate students, a change may be made only with the approval of the Dean of Graduate Studies, in consultation with the Graduate Studies Committee.

Grades of E and I shall not be considered in calculating a student's grade-point average.

Petitions and Exceptions

Once recorded, a grade will only be changed on the basis of error. For undergraduates, a change may be made only with the approval of the Undergraduate Academic Standards and Honors Committee.

Petitions by undergraduate students for late drops (i.e., requests to drop a course after Drop Day) will be considered by the UASH Committee, but will only be approved if circumstances beyond the student's control prevented them from dropping a course or courses by the posted deadline. Such petitions must be submitted before the end of the term following the term when the course was taken, or within the first term of return, if the student is on leave in the term following the term when the course was taken. If approved, a W will be recorded on the student's transcript in place of a grade for that course. W's will not be included in the computation of the student's grade-point average. Courses will be expunged from the student's record only in exceptional circumstances, at the discretion of the UASH Committee.

Petitions from graduating seniors submitted later than the first UASH meeting following graduation (which normally takes place shortly after graduation) will not be accepted for consideration, except to correct an error by the Institute.

Grade-Point Average

Grade-point average is computed by dividing the total number of credits earned in a term or an academic year by the total number of units taken in the corresponding period. Units for which a grade of F has been received are counted, even though the course may have subsequently been repeated. Grades of P or F obtained in courses graded on a pass/fail basis are not included in computing grade-point average.

Each course at the Institute is assigned a number of units corresponding to the total number of hours per week devoted to that subject, including classwork, laboratory, and the normal outside preparation. Credits are awarded as shown in the table below.

No. of Units	A+	A	A-	B+	B	B-	C+	C	C-	D+	D	F
1	4	4	4	3	3	3	2	2	2	1	1	0
2	9	8	7	7	6	5	5	4	3	3	2	0
3	13	12	11	10	9	8	7	6	5	4	3	0
4	17	16	15	13	12	11	9	8	7	5	4	0
5	22	20	18	17	15	13	12	10	8	7	5	0
6	26	24	22	20	18	16	14	12	10	8	6	0
7	30	28	26	23	21	19	16	14	12	9	7	0
8	35	32	29	27	24	21	19	16	13	11	8	0
9	39	36	33	30	27	24	21	18	15	12	9	0
10	43	40	37	33	30	27	23	20	17	13	10	0
11	48	44	40	37	33	29	26	22	18	15	11	0
12	52	48	44	40	36	32	28	24	20	16	12	0
13	56	52	48	43	39	35	30	26	22	17	13	0
14	61	56	51	47	42	37	33	28	23	19	14	0
15	65	60	55	50	45	40	35	30	25	20	15	0

Pass/Fail Grading, the following regulations apply

- First-quarter and second-quarter First-Year students receive pass/fail grades in all Core and introductory courses listed by virtue of their classification as First-Year students by an admissions committee or, for students whose status after the first year is uncertain, by the Undergraduate Academic Standards and Honors Committee.
- All other students, undergraduate and graduate, in courses with numbers under 200 will receive letter grades unless the course is designated "graded pass/fail'' or unless, when it is allowed, the student submits a change to the course's grading scheme on or before Drop Day.
- In courses with numbers 200 or greater that are not designated either "graded pass/fail" or "letter grades only," the instructor may decide separately for each student what class of grades to use.
- All research courses shall be designated "graded pass/fail.'' All reading courses, seminar courses, or other courses that do not have a formal class structure shall be designated "graded pass/fail'' unless the option secures an exemption from the Curriculum Committee or the Graduate Studies Committee and

from the Faculty Board.

- A grade on the pass/fail system should be P if it would have been a D or better on the letter grade system. (Note that there is no D– grade.) The standards of failure in courses in which only pass/fail grades are used should be the same as they would be if the course were letter graded.
- Any instructor may, at their discretion, specify prior to registration that their course, if not classified by the above regulations, is to be graded on a "letter grades only" basis or is to be graded pass/fail only, subject to possible review by the responsible option. The registrar must be notified of such specification two weeks before the beginning of registration. (Note: A course's grading scheme is not changed after it has begun.)
- Each term, any student may select, subject to requirements imposed by the student's option, two elective courses in which they are to be graded on a pass/fail basis if the course is not designated as "letter grades only" and is not specifically required for the degree in their option. To make this election, a student must submit a change to the course's grading scheme in REGIS, or submit a written request to the Registrar's Office, on or before Drop Day. This election may be reversed or reinstated at any time before the deadline. Students must resubmit their schedule in REGIS after all changes, and the pass/fail election must be approved by the student's adviser. The instructor must allow any eligible student to make this election.
- Of the units offered to satisfy the requirements for the Bachelor of Science degree, no more than 90 may be in courses graded pass/fail because of the student's election (this does not include those courses taken in the first two terms during an undergraduate's first year (as a first-year student) or those designated pass/fail by the instructor, option, or curriculum committee).
- The Institute has approved changes to the Core Curriculum for the incoming class entering 2024. If you are interested, the details may be found in Appendix A.

Procedures for Resolving Disputes over Grading

At Caltech, the instructor has full responsibility for assigning grades to students enrolled in a course. On occasion, a student may not understand how a grade was determined and may seek further information. The student should first meet with the instructor or teaching assistant to discuss the grade. If after doing so the student believes the grade is unjustified or capricious, the following procedures are available.

Before the end of the term following the term when the grade was issued, the student should contact the academic mediator, appointed by the provost, who will work with the student and instructor to resolve the problem. If the mediation effort is unsatisfactory to the student, they may request a formal review by an appropriate executive officer or academic officer. The executive officer will review the case and report the decision in writing to the student. If the executive officer

decides that a change of grade is warranted, or if the student requests a further appeal, these shall be requested of the division chair. At the discretion of the division chair, a committee may be appointed to review the case. The committee members should interview everyone involved in the case (the student, the course instructor, the teaching assistant, and anyone else with relevant information), and make a written recommendation to the division chair. Only the division chair can authorize the registrar to enter a new grade in the student's transcript.

https://catalog.caltech.edu/current/general-information/grades-and-grading/#e-and-i-grades

Changes in Registration (Course Withdrawals)
34 CFR 668.34(a)(6)

All changes in registration must be reported to the Registrar's Office by the student prior to the published deadlines. A grade of F will be given in any course for which a student registers and which they do not either complete satisfactorily or drop. A course is considered dropped when a student drops the course in REGIS or notifies the Registrar's Office in writing. A student may not at any time withdraw from a course that is required for graduation in their option, without permission of the registrar.

A student may not add a course after the last day for adding courses or withdraw from a course after the last date for dropping courses, without the approval of the Undergraduate Academic Standards and Honors (UASH) Committee. In cases where the late addition of a course would have put the student in a position of overload by Add Day of the term concerned, the student must also obtain an approved retroactive overload from the dean or associate dean of undergraduate students. Registration for added courses is complete when a student registers for the course on REGIS or sends a written request to the Registrar's Office with the proper approvals. No credit will be given for a course for which a student has not properly registered. The responsibility for registering or dropping courses (in REGIS or by direct communication with the Registrar's Office) is on the student. Failure to fulfill the responsibility because of oversight or ignorance is not sufficient grounds to petition for permission to drop or add courses after the deadline.

https://catalog.caltech.edu/current/information-for-undergraduate-students/registration-regulations/

Undergraduate Student Leaves of Absence
General Information

Formal separation from the Institute is effected by filing a completed undergraduate student leave form to be forwarded to the registrar and other appropriate offices. The effective date of a withdrawal is entered by the undergraduate dean or designee. A student withdrawing from the Institute at any time during the term without filing a formal undergraduate leave form will not be considered withdrawn. In such a case, any grades reported by the instructors will be recorded on the official transcript, and the grade of F will be

recorded for all other courses.

A student who withdraws or is absent for a term (or longer), without an approved undergraduate student leave must petition for reinstatement to return to the Institute. Reinstatement rules are listed under scholastic requirements. Return from involuntary, medical and/or personal leave requires approval through the Undergraduate Deans' office.

If the withdrawal occurs after Add Day of any term, a W (standing for "withdrawn") will be recorded on the student's transcript for all courses in which the student is enrolled. A grade of W is not included in the computation of the student's grade-point average. The record will also indicate whether an undergraduate student leave was granted.

Caltech considers students on an approved leave to be matriculated; however, students on leave for any reason are not currently enrolled and therefore do not enjoy all the rights and privileges of enrolled students. Unenrolled students, and accordingly, students on leave, have limited access to Caltech's educational activities, programs, and services. In some cases, the dean or designee may also require that unenrolled students apply for permission in advance of visiting campus.

Students on leave should only be on campus as an occasional visitor. Students on leave may not attend classes or labs, live in Institute housing, retain leadership positions, or access certain student resources, including Student Wellness Services or Residential Experience activities or programs during their leave.

They also may not obtain employment or do volunteer work on campus unless they have been given permission to do so via an approved "Permission to Participate while on Leave" Form: https://deansoffice.wufoo.com/forms/request-to-participate-while-on-leave/. Failure to gain a dean's permission to be active on campus will be considered when a student on any type of leave applies to return.

Career Achievement, Leadership and Exploration (CALE) is, by default, open to all students who have not been permanently separated from the Institute, regardless of leave or enrollment status, unless otherwise revoked by the Director of CALE or the deans' office.

Students may consult with their advisor and otherwise plan for their academic future; however, they will not receive credit for courses unless they are properly enrolled. Students who are on leave are still subject to all Institute policies, including the Institute Sex- and Gender-Based Misconduct Policy. Violations of policy while on leave may affect a student's eligibility to re-enroll.

Voluntary Leaves

Personal Leaves

A student may request a voluntary leave of absence for personal reasons (personal leave) by submitting a written petition via completion of the undergraduate student leave form. International students should consult with the International Student Programs Office regarding visa implications prior to submitting the leave petition.

The deans may grant a personal leave provided (a) the student is in good standing, in other words does not have to meet special academic or disciplinary requirements as a result of reinstatement, (b) the leave is for one year or less, although special circumstances can be considered for a longer leave, and (c) the leave extends over a period that includes at least one full term. Leaves will not be granted retroactively and must be filed by the last day of classes of the term.

Students who elect to take a personal leave while involved in pending conduct processes will be expected to participate in the pending conduct process until its completion. However, the Deans' Office may excuse students from participation while on personal leave if extenuating circumstances justify the pause.

A petition to return from a personal leave should be submitted six (6) weeks before the first day of the term for which the student intends to return. Return from a personal leave is subject to the approval of the Deans' Office.

Medical Leaves

If a student is unable to complete their coursework due to medical reasons, the student may petition for a medical leave of absence by submitting a written petition via completion of the undergraduate student leave form. International students should consult with the International Student Programs Office regarding visa implications prior to submitting the medical leave petition.

The duration of a medical leave should be determined primarily by the student's improvement in treatment. In general, however, medical leaves are expected to include at least one full term.

The Institute may impose conditions on return from a medical leave, which may include confirmation from the student's health care provider that the student is following the recommended course of treatment, the student's consent for the provider to discuss the student's condition or progress during the leave with Caltech officials, including representatives of Student Wellness Services and the Deans' Office, and an independent evaluation of the student's readiness to return by a qualified medical professional. Any conditions of return will be specified at the time of the leave approval.

To request a leave, a student can take the following steps:

1. Submit the leave form.
2. The student should then meet with either:

- The Medical Director of Health Services or designee (for leaves related to medical conditions), or
- The Clinical Director of Counseling Services or designee (for leaves related to emotional, psychological, or psychiatric conditions).

This meeting is to help the student make plans for their treatment during their leave, to discuss the need for any conditions placed on the leave, and to answer any questions the student has about the leave process. After this meeting, the student should give written consent for the Director to communicate their recommendation to the

Deans' Office by filling out the release of information and records consent form available on the Student Wellness website.

1. The Dean or designee may then authorize the medical leave.
2. If a student taking medical leave wants to participate in any Caltech educational activities, programs or services, they must meet with a dean and other appropriate administrators to determine any necessary support or accommodations needed while on leave and submit a "*Petition to Participate While on Leave*" for approval. Failure to gain a dean's permission to be active on campus will be considered when a student on leave applies to return.

While on Medical Leave

It is the expectation that a student on medical leave will focus on managing the condition(s) that precipitated the leave. Any impending or ongoing conduct processes will ordinarily be suspended while a student is on medical leave, unless the student requests otherwise in writing, and their medical provider agrees it is appropriate.

Return from Medical Leave

This requires the following steps:

1. Submitting a completed Return from Medical Leave form to the deans.
2. Signing a release of information form authorizing any treatment providers to communicate with Caltech, including representatives of Health and Counseling Services to determine the student's readiness to return and recommendations for reasonable accommodations. This form is available on the Student Wellness Services website.
3. Submitting a provider recommendation form to either the Medical Director of Student Health Services or the Clinical Director of Student Counseling Services, or their designee. The student's healthcare provider should fill out this brief form to summarize their work together; to outline any progress the student has made in treatment; and to state any recommendations for returning to the Institute. This form is available on the Student Wellness Services website.
4. After Student Wellness Services has received the provider recommendation form, the student should schedule a meeting with either the Medical Director of Health Services or designee (for leaves related to medical conditions), or the Clinical Director of Counseling Services or designee (for leaves related to emotional, psychological, or psychiatric conditions). In this meeting, the student and the Director will discuss their healthcare provider's recommendations and will discuss the need for any continued treatment. The student should sign a release of information form allowing the Director to communicate a summary of this meeting to the deans. This form is available on the Student Wellness Services website.

5. Final approval of the petition is the responsibility of the dean or designee.

A student returning from a leave for medical reasons will maintain the same academic standing that they had previously-i.e., if on academic probation, the student will remain on probation upon return from leave.

Pregnancy Leave

Consistent with Caltech policy and the requirements of Title IX, students who are unable to complete their coursework or other course of study for a period of time due to a pregnancy, childbirth and related medical conditions are eligible for a medical leave of absence. Students who are pregnant or who have recently given birth are also eligible for reasonable accommodations.

A pregnant student who wishes to take a medical leave should submit a completed after obtaining a recommendation from the Medical Director of Health Services. Medical documentation from the student's treating medical provider is required.

The Institute also provides reasonable accommodations to pregnant students consistent with federal and state law. Reasonable accommodations may include allowing pregnant students to maintain a safe distance from hazardous substances, allowing them to make up tests and assignments that are missed for pregnancy-related reasons or excusing of absences that are medically necessary.

Bonding

An enrolled student in good academic standing who chooses to take a leave of absence because of the birth of his or her child may request a bonding leave by submitting a completed petition form for approval.

Involuntary Leave

The dean or designee may determine that it is necessary to place a student on an involuntary leave in a variety of circumstances, including when a student demonstrates behavior that poses a threat to health or safety, causes significant disruption to the Caltech community, for the personal safety or welfare of the student involved, as an interim measure, or as a result of a disciplinary action.

The dean may impose an involuntary leave in appropriate circumstances, such as where a student's behavior: (1) has, or threatens to, cause significant property damage; (2) significantly disrupts the Caltech community; (3) presents a substantial risk of harm to self or others; (4) indicates the student is unable or unwilling to carry out self-care obligations; or (5) violates a Caltech policy or the honor system. An involuntary leave also may be imposed when that the student requires a level of care from the Institute community that exceeds the reasonable accommodations, resources and staffing that the Institute can reasonably be expected to provide for the student's well-being.

Review and Decision Process
In making an informed decision to place a student on involuntary leave in such circumstances, the dean will conduct an individualized assessment and consider relevant information including information provided in a timely manner by the student. If the conduct has been the subject of an investigation under an Institute process or procedure, the dean will consider the findings and conclusions reached in that process.

The dean may consult with other Institute personnel, including but not limited to, security and residential life personnel, staff, faculty, and other individuals or departments. If appropriate and feasible, the dean may seek cooperation and involvement of parents or guardians of the student.

Medical information, including medical information provided in a timely manner by the student, may be considered if the behavior is associated with a physical or mental condition. In appropriate cases, the dean may consult with the director of Wellness Services, or designee, and/or require a physical or mental evaluation from a health professional if the dean believes such an evaluation is necessary to make an informed decision. Students are expected, if necessary, to sign a release of information to facilitate discussions between Caltech and the health professional conducting the evaluation. The dean will also consider whether relevant risk factors can be eliminated or reduced to an acceptable level through reasonable accommodation.

Emergency Leave
If the dean determines that a student's continued presence is likely to pose a substantial risk to the safety and well-being of the student or others, the dean may place the student on an emergency interim leave before a final determination is made. The dean will make reasonable attempts to meet with the student and consider relevant information, including in appropriate cases medical information provided by the student, before deciding on an emergency interim leave. An emergency interim leave will remain in effect until a final decision has been made.

While on Leave
A student placed on involuntary leave as a disciplinary sanction will not be allowed to participate in Caltech educational activities, programs or services without the express permission of the dean or designee. Requests for an exception to this policy should be discussed at the time of the leave decision, and a "Petition to Participate While on Leave" must be approved prior to any such participation. Failure to gain permission, and consequently being active on campus, will be taken into consideration when a student on involuntary leave applies to return. The same applies to students placed on involuntary medical leave.

Return from Leave
A student on involuntary leave will not be allowed to return until the dean makes a fact-specific assessment of the circumstances, considers relevant risk factors, and concludes that the student does not pose a significant disruption to the functioning of the Institute community and/or does not pose a substantial risk to the health and safety of the student or others. The dean will consider relevant information, including information provided by the student. In cases where a student has a physical or mental condition associated with the behavior triggering the leave, the dean will also consider whether the relevant risks can be eliminated by a reasonable accommodation. The student will be notified in writing if the dean determines that the student will not be permitted to return from a leave or will be permanently separated from the Institute.

Appeal
A decision by the dean to place a student on involuntary leave may be appealed in writing within ten days to the vice president for student affairs (or designee). If the leave is imposed as a sanction resulting from a finding of responsibility under an Institute process any applicable limitations on grounds for appeal will apply.

Course Repetitions
34 CFR 668.34(a)(6)

Failed. Means that no credit will be recorded for the course. The units, however, count in computing the student's grade-point average, unless the course was taken on a pass/fail basis. The student may register to repeat the subject in a subsequent term and receive credit without regard to the previous grade, the new grade and units being counted as for any other course, but the original F and units for the course remain on the record.

https://catalog.caltech.edu/current/general-information/grades-and-grading/

Transfer of Credit
34 CFR 668.34(a)(6)

The courses for which enrolled transfer students will receive credit, and the corresponding class standing, will be determined at the time of enrollment. Final transcripts must be submitted to Undergraduate Admissions. Syllabi must be submitted to the Registrar, who will present the material to the faculty for evaluation. After a student is admitted, they may work with Admissions to obtain a preliminary evaluation of class standing. Preliminary class standings are not guaranteed. Actual class standing will be based upon the formal transfer credit evaluations over the summer. If the standard of work taken elsewhere is uncertain, additional examinations may be required before the question of credit is finally determined. Once a student has enrolled, faculty members review each course submitted for credit on an individual basis. Therefore, we cannot answer questions about the acceptance of coursework from other institutions prior to admission.

All transfer students must complete at least 216 units at Caltech, regardless of the number of units they are transferring in from another institution.

Graduation Requirements
Admitted transfer students must meet the following requirements in order to receive a Caltech Bachelor of Science degree.

A Caltech undergraduate degree is based on a four-year residential experience (study abroad included) in which students have the time to explore their academic interests in a deep and rigorous way. Students who are admitted as transfer students or 3/2 students may be granted advanced standing and term credit for academic work accepted in transfer to Caltech. However, transfer and 3/2 students must enroll for a minimum of six terms at Caltech. Any exceptions must be approved by the dean of undergraduate students and the vice president for student affairs.

Regardless of the amount of credit awarded upon matriculation, transfer students must spend at least two years (six terms) in residence at Caltech. Students must also earn at least 216 units at Caltech, not including courses taken to satisfy math and science core curriculum requirements.

Students must take, or have taken the equivalent of, all core curriculum courses.

Students must satisfy all of their chosen option's degree requirements. Transfer students may choose from among all Caltech undergraduate options.

https://catalog.caltech.edu/current/information-for-undergraduate-students/admission-to-upper-classes-by-transfer/#transfer-of-credit

Allowance and Transfer of Credit
34 CFR 668.34(a)(6)

Transfer of Credit from Other Institutions
Regularly enrolled students who want to obtain credit for college courses taken elsewhere should obtain the permission of the dean of students and have a copy of the transcript of their work sent to the Registrar's Office. The student should then obtain an Allowance of Credit form from the Registrar's Office and take this, with the transcript as well as any supporting class materials required by the option representative, to the representative of the option in which credit is desired. Pending approval by the option representative, credit will be granted when the Allowance of Credit form, with the appropriate signatures, is returned to the office.

Allowance of Credit in the Humanities and Social Sciences
In general, Caltech students should fulfill Caltech course requirements by taking courses at Caltech. Students are expected to have a well-reasoned educational goal for taking classes elsewhere. The only exceptions are transfer students admitted to advanced standing. Credit for comparable work done at other institutions with similar academic standards is not granted automatically.

Students who wish to take courses elsewhere (whether on leave, in the summer, or during the academic year) should consult, in advance, with the executive officer for the humanities or the executive officer for the social sciences, or their designees, to minimize any misunderstanding regarding the nature of credit they may receive. Upon completion of the course, the student must obtain an Allowance of Credit form from the registrar, obtain the signed approval of the executive officer, or their designee, for transfer credit, and return the completed form to the Registrar's Office. The executive officers are the final authority in the allowance of credit in HSS courses.

Guidelines and specific information about allowance of credit are available from the Division of the Humanities and Social Sciences.

Other Allowances of Credit

Except for transfer credit and credit based on Caltech placement exams upon admission, credit will not be granted for Caltech courses in which the student is not officially enrolled, except in special circumstances by arrangement with the instructor. Such arrangements must be approved by the Curriculum Committee, and the student must petition the Committee before the work is undertaken.

https://catalog.caltech.edu/current/information-for-undergraduate-students/scholastic-requirements/#allowance-and-transfer-of-credit

Change of Major

Change of Option

An undergraduate in good standing at the Institute shall be permitted to transfer into any option of their choice provided they have (a) a 1.9 GPA in subjects required for graduation in that option or in a specific group of subjects designated by that option or (b) permission of the option representative or committee. A change of option is effected by obtaining a Change of Option petition from the Registrar's Office. The completed petition must then be signed by the option representative for the new option (who will assign a new adviser), and filed with the Registrar's Office. Institute regulations require that a student who has made normal progress at the Institute be able to change options at any time up to the end of the sophomore year without penalty either as to time until graduation or as to excessive unit requirements in any term.

Additional Degrees

Joint B.S./M.S. Degree

In exceptional cases, undergraduate students may be eligible to pursue a joint B.S./M.S. program of study to be completed within the four years (12 terms) of the undergraduate program. The M.S. degree may be in a different field than the B.S. option. Students should contact the respective graduate Option Representative to find out if the joint B.S./M.S. degree is offered in a particular option by the start of junior year. If so, students must follow the normal procedures for admission to the graduate program. Students admitted to the joint B.S./M.S. degree must complete a minimum of 486 units for the bachelor's program and an additional 135 units for the master's

program with no overlapping of courses. In addition, a written plan of study must be submitted to the Registrar's Office for approval no later than the fall term of the senior year. The plan of study should provide detail of the courses that are proposed to satisfy each degree requirement within the 12 terms of the bachelor's program and once approved shall constitute the requirements for the degree. Additional terms and overloads are not permitted. Any changes to the plan require written approval by the Registrar. If not completed within the four years, students will be removed from the joint program and they, and all their courses, will be attached to the bachelor's program. Students enrolled in the joint B.S./M.S. degree will be considered undergraduate students and will not be eligible for graduate financial aid, graduate housing, or other graduate student privileges.

Caltech only offers B.S. Degrees so students cannot double major in an undergraduate program.

Remedial Courses

Caltech's SAP calculation does not include remedial courses since all courses offered at the Institute are considered college level.

CLASS LEVEL FOR FINANCIAL AID PURPOSES

Undergraduate students are classified according to the number of units earned and the number of terms in residence at Caltech. Both these criteria must be satisfied for class-level eligibility. Students are regarded as first-year until eligible for sophomore status, and as sophomores, juniors, or seniors if they meet the corresponding criteria set below. Units earned are defined as units completed with a passing grade.

Classification	Minimum Units Earned	Minimum Terms in Residence
Sophomore	108	3
Junior	216	6
Senior	324	9

PART-TIME ENROLLMENT (UNDERLOADS)

The Institute will charge students for a minimum of 12 terms of full-time tuition, or the prorated equivalent based on their classification at the time they begin their enrollment, even if they complete their degree requirements early. Undergraduate students who underload in a term will be charged full-time tuition but their financial aid, including outside scholarships, will be adjusted as indicated below based on the actual number of units students are enrolled in as of Add Day. Students may NOT receive scholarship assistance for any term in which they are not enrolled at least half-time.

Underloads and Financial Aid: The Impact of Less than Full-time Enrollment

Any student who wishes to carry fewer than 36 units in any given term must petition for an underload. Underloads must be approved by the Deans. Underloads for graduating seniors must be approved by the Registrar. Petitions are available online and in the Deans' Office.

PLEASE NOTE: The Institute will charge students for a minimum of 12 terms of full-time tuition, even if they complete their degree requirements early. Students may NOT receive scholarship assistance for any term in which they are not enrolled at least half-time.

Undergraduate students who underload in a term will have their financial aid, including outside scholarships, adjusted as indicated below, based on the actual number of units students are enrolled in as of Add Day. ***However, the student's Caltech account will be charged full-time tuition.***

The following information summarizes the impact of less than full-time enrollment.

The reduction in financial aid is generally done in the following order:

1. Federal Pell Grant
2. Caltech scholarships in the current term
3. Caltech scholarships awarded in other terms
4. Self-help aid (such as loans and work-study)

If the necessary reduction is greater than the total amount of financial aid you were awarded for the year, you will lose all of your financial aid for the current academic year.

3/4 Time

Full-time enrollment is defined in the Caltech Catalog as 36 units. Students enrolling less than full-time, taking between 27 to 35 units, are considered enrolled 3/4 time. The impact to their financial aid is usually a reduction to their grant, in the same amount as the tuition reduction on their student aid budget. Federal Pell Grant recipients will have their Federal Pell award reduced according to federal regulations. The Financial Aid Office will revise the student's budget to reflect the reduction in tuition, calculated based on the units enrolled in as of Add Day, and then revise the student's aid (grant eligibility) to reflect the reduction in need. ***However, the student's Caltech account will be charged full-time tuition.***

1/2 Time

Half-time enrollment is defined as enrolling in 18 to 26 units. In this situation, the Financial Aid Office will revise the tuition amount on the student aid budget and also reduce the student's books and supplies allowance to one half of the standard amount for that term. The student's aid is adjusted to reflect the reduced financial aid eligibility. Federal Pell Grant recipients will have their Pell award reduced according to federal regulations. The Financial Aid Office will revise the student's financial aid budget and then revise the student's aid (grant

eligibility) to reflect the reduction in need. ***However, the student's Caltech account will be charged full-time tuition.***

Less than 1/2 Time
Less than 1/2 time enrollment is defined as taking fewer than 18 units. Tuition is revised based on the units enrolled in as of Add Day. As indicated in the Caltech Catalog, the minimum tuition charge is 10 units per term. The books and supplies allowance is reduced to 1/4 for that term. The student's aid is reduced based on the reduced student aid budget. Federal Pell Grant recipients will have their Pell award reduced according to federal regulations. More importantly, the student becomes ineligible for Caltech grant aid for that term; the student will only be eligible for Caltech work study and/or loan assistance. If the student is enrolled less than half time, the grace period on any student loan (CIT loan, Institute loan and Federal Stafford loan) will begin. In addition, a student/family is no longer eligible for Federal PLUS or Stafford loans during periods of less than ½ time enrollment. ***However, the student's Caltech account will be charged full-time tuition.***

Effect on Outside Scholarships
In all of the above categories, the Financial Aid Office also checks to see if a student has an outside scholarship that requires continuous full-time enrollment. If a scholarship donor requires full time enrollment, the Financial Aid Office is required to return the scholarship money for that term to the donor. If this occurs, the student is encouraged to contact the donor directly to review and, possibly, appeal the agency's policy.

Questions
Students with questions regarding underloads should discuss their individual circumstances with a Financial Aid Counselor. Contact our office with any questions you have.

PRIZES AND AWARDS

THE CALTECH Y ADVOCATING CHANGE TOGETHER (ACT) AWARD

The Caltech Y Advocating Change Together (ACT) Award provides students with the opportunity to learn about a global, national, or local issue by immersing themselves with activists working on a cause.

ROBERT P. BALLES CALTECH MATHEMATICS SCHOLARS AWARD

This award is given to the mathematics major finishing their senior year who has demonstrated the most outstanding performance in mathematics courses completed in the student's time at Caltech.

MABEL BECKMAN PRIZE

Given in memory of Mabel Beckman's many years of commitment to Caltech's educational and research programs, this prize is awarded to an undergraduate woman (or women) who, upon completion of her junior or senior year at Caltech, has achieved academic excellence and demonstrated outstanding leadership skills, a commitment to personal excellence, good character, and a strong interest in the Caltech community.

ERIC TEMPLE BELL UNDERGRADUATE MATHEMATICS RESEARCH PRIZE

This prize is given to one or more juniors or seniors for outstanding original research in mathematics.

BHANSALI PRIZE IN COMPUTER SCIENCE

Established in 2001 by Vineer Bhansali (B.S. '87, M.S. '87) in memory of his grandfather, Mag Raj Bhansali, this prize is given to an undergraduate student for outstanding research in computer science in the current academic year. Awardees are selected by a committee of computer science faculty.

AMASA BISHOP SUMMER STUDY ABROAD PRIZE

This prize is given to one or more first-year students, sophomores, or juniors to fund summer study abroad in an organized program with the aim of gaining exposure to foreign language and international issues or cultures, including global issues in the sciences and engineering.

RICHARD G. BREWER PRIZE IN PHYSICS

This prize recognizes a first-year student with the most interesting solutions to the Physics 11 "hurdles," demonstrating intellectual promise and creativity at the very beginning of their Caltech education.

FRITZ B. BURNS PRIZE IN GEOLOGY

This prize is given to an undergraduate who has demonstrated both academic excellence and great promise of future contributions in the fields represented by the Division of Geological and Planetary Sciences.

THE CALTECH Y RISE SERVICE AWARD

The Caltech Y Rise Service Award recognizes exceptional service provided by Rise Program tutors. This award highlights the dedication and outstanding contributions of individuals who exemplify the Caltech Y's commitment to service.

BONNIE CASHIN PRIZE FOR IMAGINATIVE THINKING

Awarded annually, this prize is given to the entering first-year student who wrote the most imaginative essays in the application for their first-year admission.

THE CCID ACTIVIST SCHOLAR AWARD

This award is given to individuals who demonstrated excellence within their discipline and research while engaging in complex social justice issues. This awardee has led or participated in advocacy campaigns centering on the experiences of minoritized identities and provided vision and leadership in forming affinity spaces and targeted support programs.

THE CCID AGENT OF CHANGE AWARD

This award is given to individuals embodying servant leadership through a demonstrated commitment to steering institutional change within the Caltech community. This person takes the initiative and has the vision to translate a need into actionable steps or policy to create a legacy and a more inclusive campus climate.

ROBERT F. CHRISTY PRIZE FOR AN OUTSTANDING FIRST-YEAR IN PHYSICS

This prize is awarded annually to a first-year student who has demonstrated excellence in physics. Established in 2018, this prize honors the memory of Robert F. Christy, former provost and professor of theoretical physics at Caltech.

ROBERT F. CHRISTY PRIZE FOR AN OUTSTANDING SENIOR IN THEORETICAL PHYSICS

This prize is awarded annually to a senior who has demonstrated excellence in theoretical physics through research and/or coursework. Established in 2018, this prize honors the memory of Robert F. Christy, former provost and professor of theoretical physics at Caltech.

DONALD S. CLARK MEMORIAL AWARDS

This award is given to two juniors in recognition of service to the campus community and academic excellence. Preference is given to students in the Division of Engineering and Applied Science and to those in chemical engineering. The awards honor the work of Professor Clark, class of 1929, both in the field of engineering and in his service to the Alumni Association.

CMS AND IST GRADIENT FOR CHANGE AWARD

The CMS and IST Gradient for Change Awards honor students, postdocs, staff, and faculty in the Caltech community who demonstrate exceptional efforts to make Caltech and/or the broader scientific community a more diverse, equitable, and inclusive environment. The awards recognize and highlight individual contributors or small teams who are considered agents of change, community leaders, and/or allies to historically marginalized group(s) in the information sciences, including computer science, applied mathematics, and beyond.

DEANS' CUP

This award is presented to undergraduates whose concern for their fellow students has been demonstrated by their persistent efforts to improve the quality of undergraduate life and by effective communication with members of the faculty and administration.

EAS NEW HORIZONS DIVERSITY, EQUITY & INCLUSION AWARD

This award recognizes and honors individuals within the EAS community who have actively contributed to the Division's goal to be a diverse, equitable and inclusive engineering community.

DORIS EVERHART SERVICE AWARD

This award is given annually to an undergraduate who has actively supported and willingly worked for organizations that enrich not only student life, but also the campus and/or the community as a whole, and who has, in addition, exhibited care and concern for the welfare of students on a personal basis. The award was established in 1999 by Martin and Sally Ridge in honor of Doris Everhart.

RICHARD P. FEYNMAN PRIZE IN THEORETICAL PHYSICS

This prize is awarded to a senior on the basis of excellence in theoretical physics.

HAREN LEE FISHER MEMORIAL AWARD IN JUNIOR PHYSICS

This recognizes a junior physics major who demonstrates the greatest promise of future contributions in physics.

HENRY FORD II SCHOLAR AWARDS

This award recognizes engineering students with the best academic record at the end of the third year of undergraduate study.

JACK E. FROEHLICH MEMORIAL AWARD

This award, established by the family and friends of the late Jack E. Froehlich (B.S. '47, M.S. '48, Ph.D. '50), who did his undergraduate and graduate work at Caltech and was later the project manager for Explorer I for the Jet Propulsion Laboratory, provides an award to one or two juniors in the upper 5 percent of their class who show outstanding promise for a creative professional career. The recipients are selected by the deans and the Undergraduate Academic Standards and Honors Committee.

DR. ALLEN AND CHARLOTTE GINSBURG SCHOLARS

This award is given to rising seniors with academic excellence and outstanding leadership skills who have participated in the visual and performing arts program.

BARRY M. GOLDWATER SCHOLARSHIP

The Goldwater Scholarship Program, one of the oldest and most prestigious national scholarships in the natural sciences, engineering, and mathematics in the United States, seeks to identify, encourage, and financially support college juniors and seniors who show exceptional promise of becoming this Nation's next generation of research leaders in these fields.

GEORGE W. AND BERNICE E. GREEN MEMORIAL PRIZE

This prize, awarded annually, recognizes an undergraduate student in any class for original research, an original paper or essay, or other evidence of creative scholarship beyond the normal requirements of specific courses. The student is selected by the deans and the Undergraduate Academic Standards and Honors Committee.

DAVID M. GRETHER PRIZE IN SOCIAL SCIENCE

The prize rewards outstanding performance and creativity by a Caltech undergraduate who completes one of the social science options. The prize was established by Susan G. Davis in recognition of David M. Grether's contributions to econometrics and experimental economics and his service to the Division of the Humanities and Social Sciences. The prize is awarded annually by a committee of social science faculty.

THE CALTECH Y LUCY GUERNSEY AWARD

This award recognizes graduate and undergraduate students who have provided exceptional service to the Caltech Y and/or the community. Recipients are selected based on their active involvement in Caltech Y service projects, demonstrated leadership in community and volunteer service efforts, and a strong spirit of service.

FREDERIC W. HINRICHS, JR., MEMORIAL AWARD

This award, established by the Board of Trustees, is in memory of Frederick W. Hinrichs, Jr., who served for more than 20 years as dean and professor at Caltech. In remembrance of his honor, courage, and kindness, the annual award is given to the senior (or seniors) who, throughout their undergraduate years, made the greatest contribution to the student body and whose qualities of character, leadership, and responsibility have been outstanding. At the discretion of the dean, more than one award may be made in any year.

ALEXANDER P. AND ADELAIDE F. HIXON PRIZE FOR WRITING

The Hixon Prize for Writing was established in 2000 by Alexander P. and Adelaide F. Hixon. The prize will be awarded annually to an undergraduate student for the best composition in a first-year humanities course. The prize is administered by the writing center, and the winner will be chosen by a committee from the humanities division.

THE HOUSES AND RESIDENCES IDEA AWARD

he Houses and Residences IDEA Award celebrates exceptional individuals who excel in fostering a vibrant and inclusive environment within the Houses and Residences. Their unwavering commitment ensures that each resident feels a deep sense of belonging and support. These leaders drive positive transformation by nurturing inclusive dialogues and instilling a strong sense of community through advocacy. Through their efforts, they create an environment where everyone can flourish in Houses and Residences.

THE GEORGE W. HOUSNER PRIZE FOR ACADEMIC EXCELLENCE AND ORIGINAL RESEARCH

This prize is given annually to a senior or seniors in the upper 20 percent of their class who have demonstrated excellence in scholarship and in the preparation of an outstanding piece of original scientific research. The students are selected by the deans and the Undergraduate Academic Standards and Honors Committee. At the discretion of the deans, more than one award may be given in any year. This prize is made possible by a gift from the late George W. Housner, Carl F Braun Professor of Engineering, Emeritus.

THE CALTECH Y PATRICK HUMMEL AND HARRY GRAY TRAVEL FUND

Initiated by the Hummel Family to honor Harry Gray, Caltech's Arnold O. Beckman Professor of Chemistry and founding director of the Beckman Institute, this award was established through a generous joint gift from Carla and Paul Hummel, Patrick Hummel, and Shirley and Harry Gray. The fund supports student travel opportunities that promote professional and leadership development while broadening students' perspectives as engaged, responsible citizens of the world.

THE IDEA ADVOCATE AWARD

This award is given to individuals who promote the needs and experiences of other students, staff, or faculty to challenge systemic barriers that impede individuals from contributing their skills and talents in the classroom, workplace, or community. Such actions include raising awareness, inspiring action, advocating for an equitable campus climate, and leading efforts to dismantle structural barriers upholding oppression, and discrimination.

THE IDEA ALLYSHIP & ADVOCATE AWARD

This award is given to an individual who promotes the needs and experiences of all members of the Caltech community and challenges systemic barriers that impede members of marginalized identities from contributing their skills and talents at Caltech. Such actions include raising awareness, inspiring action, cultivating an inclusive environment, advocating for an equitable campus climate, and leading efforts to dismantle structural barriers that uphold oppression and discrimination.

THE IDEA OUTREACH & EDUCATION AWARD

This award is given to individuals who teach and inspire interest in inclusion, diversity, equity, and accessibility in the community at large through learning experiences and service. This person takes the initiative to participate in civic engagement through volunteerism, service-learning, and teaching initiatives as a change agent in the community outside of Caltech.

IDEA OUTREACH AND EDUCATION AWARD

This award is given to an individual who teaches and inspires interest in inclusion, diversity, equity, and accessibility in the community at large through learning experiences and service. This person takes the initiative to participate in civic engagement through volunteerism, service-learning, and teaching initiatives as a change agent in the community outside of Caltech.

BIBI JENTOFT-NILSEN MEMORIAL AWARD

Family and friends of Bibi Jentoft-Nilsen, class of 1989, have provided this award in her memory. This award recognizes a junior or senior who exhibits outstanding qualities of leadership and who actively contributes to the quality of student life at Caltech.

D. S. KOTHARI PRIZE IN PHYSICS

This prize is awarded to a graduating senior in physics who has produced an outstanding research project during the year.

MARGIE LAURITSEN LEIGHTON PRIZE

This prize is awarded to one or two undergraduate women who are majoring in physics or astrophysics, and who have demonstrated academic excellence.

MARI PETERSON LIGOCKI ’81 MEMORIAL AWARD

This award is given to a student who has improved the quality of student life at Caltech through their personal character. It recognizes the student who provides quiet support and kind encouragement to peers. This fund was established by Mr. Jose F. Helu Jr. (B.S. '79) to honor the memory of Mari Peterson Ligocki, who possessed these qualities.

GORDON MCCLURE MEMORIAL COMMUNICATIONS PRIZE

This prize is awarded to undergraduate students for excellence in written and oral communication skills. Awards will be given in the following fields: English, history, and philosophy.

MARY A. EARL MCKINNEY PRIZE IN LITERATURE

The Mary A. Earl McKinney Prize in Literature was established in 1946 by Samuel P. McKinney, M.D., of Los Angeles. Its purpose is to promote proficiency in writing. The terms under which it is given are decided each year by the literature faculty. It may be awarded for

essays submitted in connection with regular literature classes or awarded on the basis of a special essay contest.

MECHANICAL ENGINEERING AWARD

This award recognizes a B.S. candidate in mechanical engineering whose academic performance has demonstrated outstanding original thinking and creativity, as judged by a faculty committee appointed each year by the executive officer for mechanical engineering.

MERCK INDEX AWARD

This award is given to one or more graduating students who have demonstrated outstanding achievement in the field of chemistry.

JAMES MICHELIN SCHOLARSHIP

Given in memory of geologist James Michelin, who worked in the oil fields of Southern California in the 1930s and dreamed of returning to college at Caltech, this annual prize recognizes one or more undergraduate students for their contributions to the field of geology or geophysics.

PARK S. NOBEL PRIZE FOR EXCELLENCE IN BIOLOGY AND BIOLOGICAL ENGINEERING

This prize recognizes one undergraduate students demonstrating outstanding achievements within the Division of Biology and Biological Engineering at Caltech.

ROBERT L. NOLAND LEADERSHIP AWARD

This award is given to one or more undergraduate students who exhibit qualities of outstanding leadership, which are most often expressed as personal actions that have helped other people and that have inspired others to fulfill their capabilities. The scholarship was set up by Ametek in 1978 in honor of its president, Robert L. Noland, a Caltech alumnus.

OFFICE OF STUDENT EXPERIENCE AWARDS

These awards recognize student leaders who have made a significant impact on their Caltech community by demonstrating their efforts to improve the quality of campus life by displaying effective communication with Caltech administration and their peers. These leaders can be at any student level or within a team. They are determined by and at the discretion of the Office of Student Experience. The Office of Student Experience has presented awards such as: Student (Residential) Experience Leadership Award, Student (Residential) Experience Team Award, Student (Residential) Experience Outstanding Leader, Student (Residential) Experience Emerging Leader, Student Residential Life Award, and Student Experience Emerging Leadership.

THE OUTSTANDING MENTEE AWARD

The Outstanding Mentee Award is given to women who demonstrated a sincere desire to succeed as a researcher and is committed to her personal development, open and willing to learn from her mentor and receptive to advice and counsel, worked with her mentor to establish realistic goals and demonstrated a commitment to carrying them out.

RODMAN W. PAUL HISTORY PRIZE

The Rodman W. Paul History Prize was established in 1986 by some of his many colleagues and friends to honor Professor Paul's 35 years of teaching and research at the Institute. The prize is awarded annually to a junior or senior who has shown unusual interest in and talent for history.

HOWARD REYNOLDS MEMORIAL PRIZE IN GEOLOGY

This prize is awarded to a sophomore or junior who demonstrates the potential to excel in the field of geology and who actively contributes to the quality of Caltech student life.

CANDACE RYPISI OUTSTANDING MENTOR AWARD

This award is given to individuals who are willing to share knowledge and enhance their mentee's professional and personal development. This person has provided emotional and moral support and encouragement while improving or helping facilitate access to career-related information and exposure to various professional resources. This awardee is someone who actively promotes their mentee's sense of competence, confidence, and belonging.

HERBERT J. RYSER SCHOLARSHIPS

This scholarship is awarded to undergraduate students for academic excellence, preferably in mathematics.

SAN PIETRO TRAVEL PRIZE

This prize is awarded to one or more sophomores, juniors, or seniors to fund an adventurous and challenging summer travel experience that expands the recipients' cultural horizons and knowledge of the world.

RICHARD P. SCHUSTER MEMORIAL PRIZE

This prize is awarded to one or more juniors or seniors in chemistry or chemical engineering on the basis of financial need and academic promise.

ELEANOR SEARLE PRIZE IN LAW, POLITICS, AND INSTITUTIONS

The Eleanor Searle Prize was established in 1999 by friends and colleagues to honor Eleanor Searle, who was the Edie and Lew Wasserman Professor of History at Caltech. The prize is awarded to an undergraduate or graduate student whose work in history or the social sciences exemplifies Eleanor Searle's interest in the use of power,

government, and law.

RENUKA D. SHARMA PRIZE AND AWARD IN CHEMISTRY

This award recognizes a sophomore chemistry major for outstanding performance during their first year.

C.S. SHASTRY PRIZE IN PHYSICS

This prize is awarded to a sophomore Ph 11 alumnus, majoring in physics, to provide support for a summer research project conducted at Caltech. The winner is chosen based on passion, curiosity, and demonstrated ability.

HALLETT SMITH PRIZE

The Hallett Smith Prize was established in 1997 to commemorate Professor Smith's long career as one of this century's most distinguished Renaissance scholars. The cash prize is given annually by the English faculty to the student who writes the best essay on English Literature.

THE CALTECH Y PAUL STUDENSKI MEMORIAL AWARD

This travel grant is awarded to a Caltech undergraduate who finds themselves at a crossroads and would benefit from time away from the academic community to gain a deeper understanding of themselves and their future plans.

OLGA TAUSSKY-TODD PRIZE

This prize provides support to a female undergraduate math major for a summer experience to enrich their mathematical education.

THOMAS A. TISCH PRIZE FOR UNDERGRADUATE TEACHING IN COMPUTING AND MATHEMATICAL SCIENCES

The Undergraduate Teaching in CMS Awards were established in 2016 with a gift from Microsoft and then endowed through the generosity of Thomas A. Tisch (BS '61). The prize and honorarium are awarded to a graduate and an undergraduate student for outstanding teaching and course development in computing and mathematical sciences. Awardees are selected by a committee of CMS faculty members.

MORGAN WARD PRIZE

This prize is awarded to a first-year or sophomore who submits the best problems and solutions in mathematics.

FREDRICK J. ZEIGLER MEMORIAL AWARD

The Fredrick J. Zeigler Memorial Award was established in 1989 to honor Fredrick J. Zeigler, a member of the class of 1976 and an applied mathematics major. This award recognizes an outstanding sophomore or junior in pure or applied mathematics for their excellence in scholarship as demonstrated in class activities or in the

preparation of an original paper or essay in any subject area.

Note: Prizes and awards may be subject to federal and state income tax.

GRADUATION REQUIREMENTS, ALL OPTIONS

To qualify for a Bachelor of Science degree at the Institute, students must obtain passing grades in each of the required courses listed below; must satisfy the additional requirements listed under the undergraduate options; must complete a minimum of 486 units; and must achieve a grade-point average of not less than 1.9. Students must also register for the appropriate number of units that results in normal progress toward a B.S. degree.

The baccalaureate degree requires four years (12 terms) of academic enrollment regardless of unit load each term or the total units earned. The four-year academic enrollment requirement is separate from and in addition to any other degree requirements. Students who are admitted as transfer students or 3/2 students may be granted advanced standing and tuition credit for academic work accepted in transfer to Caltech. However, transfer and 3/2 students must enroll for a minimum of six terms at Caltech. Any exceptions must be approved by the dean of undergraduate students and the vice president for student affairs.

Under normal circumstances the core and option requirements for the B.S. degree are those stated in the catalog published in the first year of a student's enrollment at Caltech. Faculty actions or decisions taken through the Faculty Board and the relevant faculty committees may occasionally result in changes to these requirements. In the event of exceptional circumstances, changes in an individual student's graduation requirements may be sought by petition to the relevant Faculty Representative(s) through procedures administered by the registrar. Questions should be addressed to the registrar.

Students must register for the Institute requirements in the year specified, unless they have previous credit. If for some reason they are not able to complete the requirements during the proper year, they must register at the earliest possible opportunity. (The Curriculum Committee may in unusual cases excuse undergraduate students from any of the following Institute or option requirements upon presentation of petitions.)

The Institute unit system is described in the opening paragraphs of section five of this catalog.

CORE INSTITUTE REQUIREMENTS, ALL OPTIONS

A Caltech education requires not just the depth of an option, but also considerable breadth in basic science, humanities, and social science. Caltech's core curriculum prepares students for the interdisciplinary nature of contemporary research in science and technology. This encourages a culture of problem solving, collaboration, and

communication while providing valuable experience in all fields of science. Significant study in the humanities and social sciences is an important component of Caltech's core curriculum, giving alumni the ability to navigate the societal, political, and economic factors that influence, and are influenced by, their work.

The following requirements are applicable to incoming first-year students for 2025-26. Some information for continuing students has been provided as footnotes, but guidance on special cases must be sought. Courses used to satisfy core requirements may not be used to satisfy option electives.

Courses	**Units**
1. First-Year Mathematics (Ma 1 abc)[1]	27
2. First-Year Physics (Ph 1 abc)[1]	27
3. First-Year Chemistry (Ch 1 ab)[1]	15
4. First-Year Biology (Any Bi 1 course or Bi 8 and Bi 9)[1,2]	9
5. Menu Class (currently Ay 1, EE 1, ESE 1, Ge 1, or IST 4)[1]	9
6. First-Year Chemistry Laboratory (Ch 3 a or Ch 3 x)[1,3,4]	6
7. Introduction to Programming (CS 1 or CS 1 x)[3]	6-9
8. Additional Introductory Laboratory[1]	6
9. Scientific Writing	3
10. Humanities Courses (as defined below)[1]	36
11. Social Sciences Courses (as defined below)	27
12. Additional Humanities and Social Sciences Courses	36
13. Physical Education	9

[1] The Integrated Core courses (see below) satisfy the requirements for Ma 1 bc, Ph 1 abc, Ch 1 ab, Bi 1, a menu class, the first-year chemistry laboratory, the additional introductory laboratory, and one first-year humanities course.

[2] The biology core requirement can be met by any Bi 1 course. Alternatively, the requirement may be fulfilled by taking both Bi 8 and Bi 9. Nine units must be taken on grades.

[3] These courses can be taken First or Second Year as P/F.

[4] This requirement can also be met by completing Ch 4 a, Ch 8, or Ch/ChE 9.

Integrated Core

An alternative pathway to completing many of the core courses is the Integrated Core (IC), which consists of the following classes:

Courses	Units
1. Integrated Core Mathematics (IC/Ma 1 abc)[1]	18
2. Integrated Core Physics (IC/Ph 1 abc)	27
3. Integrated Core Chemistry with Laboratory (IC/Ch 1 ab)	21
4. Integrated Core Biology (IC/Bi 1 abc)	9
5. Integrated Core Geological Sciences Menu Class (IC/Ge 1 abc)	9
6. Integrated Core Introductory Laboratory (IC 3)	3
7. Integrated Core Humanities (IC/Hum 55 abc)[2]	9

[1] *Integrated Core students will also take Ma 1 a to complete their core mathematics requirements.*

[2] *Integrated Core Humanities counts as one of the two required first-year humanities courses (see below)*

In addition to the IC courses enumerated above, Integrated Core students will take Ma 1 a; CS 1 or CS 1 x; Scientific Writing, 27 units of humanities courses, 27 units of social sciences courses, 36 units of additional humanities and social sciences courses, and 9 units of physical education.

Course Load in First Year

First- and second-term first-year students will be limited to 45 units of classroom and laboratory courses. If a student chooses no electives except physical education and takes the minimum permissible laboratory courses, the total unit requirement will usually be in the range of 39 to 45. A total load - including electives - of more than 48 units per term is considered a heavy load. Loads of more than 51 units require approval by the dean of students.

Grading Policies for First-Year Students

Core courses taken in the first two terms will be graded on pass/fail. All permanent grades recorded for first-year students in Core classes during the first and second terms they are enrolled will be either P, in indicating "passed," or F, indicating "failed."

Courses taken in the first two terms from a select list of introductory courses (below) will be graded on pass/fail. If a first-quarter or second-quarter First-Year student is enrolled in a course from the list of introductory courses below, and the instructor for that courses gives letter grades, the registrar will record P for all passing grades.

The list of introductory courses to which this policy applies is: Bi 8, Ma 2, Ma 3, Ph 2ab, Ph 12ab, Ch 41ab.

Students who wish to take non-Core, non-introductory classes must take those classes according to the published grading scheme. In other words ,classes that are not part of the Core curriculum or the list of introductory classes above, even if taken in the first two quarters of the first year, can only count towards fulfilling graduation requirements if their grading scheme meets the requirement of the particular option. For example, supposed a student wants to fulfill their graduation requirements for the Computer Science (CS) option. In that case, they cannot take a CS course that is not part of the Core curriculum as pass/fail and use it to meet the requirements for that option. This is because the CS option prohibits pass/fail grading schemes for fulfilling its requirements. As a result, the student must take the CS course for a grade if they wish to fulfill the CS option requirement. Computation of grade-point averages begins at the end of the third term of the first year; the cumulative grade-point average will include any letter grades received for non-Core non-introductory classes taken for letter grades during the first two terms of the first year. First-quarter and second-quarter First-Year students receive pass/fail grades in all Core and introductory courses listed by virtue of their classification as First-Year students by an admissions committee or, for students whose status after the first year is uncertain, by the Undergraduate Academic Standards and Honors Committee.

Menu Classes

Menu classes are specifically designed for breadth. The intent of the menu class requirement is to introduce students to a subject that they did not plan to study. In many cases, it is the only class in that subject that they ever take; in other cases, they may decide to take more classes in that subject as a result. Students cannot take a menu class in a subject that they have already taken classes in or in their current option. This requirement must be completed by the end of sophomore year.

First Year Biology Requirement

All students are required to take 9 units of first-year biology, which can be satisfied by taking any course numbered Bi 1. Several different course options are available, with each Bi 1 course representing a different approach to providing an introductory understanding of the biological sciences. Bi 1 courses are offered in different terms. All Bi 1 courses may be taken pass/fail if they are taken in a first-year student's first year, independent of the term in which the course is taken. For students who are interested in a more in-depth introduction to biology, the first-year biology requirement can also be satisfied by completing both Bi 8 and Bi 9, with one of them taken for grades.

Introductory Laboratory Requirement
All students are required to take at least 12 units of laboratory work in experimental science during their first and sophomore years. Ch 3 a (6 units) or Ch 3 x (6 units) shall be taken during the first year or second years. The additional 6 units must be chosen from one of the following (or a more advanced laboratory): APh/EE 9 (6 units), APh/EE 24 (9 units), Bi 1 x (9 units but only if Bi 1 x is not being used to satisfy the biology core requirement), Bi 10 (6 units), Ch 4 ab (9 units), Ch 8 (9 units), Ch/ChE 9 (9 units), EE/ME 7 (6 units), Ge 116 (9 units), ME 8 (6 units), ME 50 ab (12 units), Ph 3 (6 units), Ph 5 (9 units), Ph 8 bc (6 units). The Integrated Core sequence also satisfies this requirement. Computational laboratory courses may not be used to satisfy this requirement.

Humanities and Social Sciences Requirements
All students must complete satisfactorily 99 units in the Division of the Humanities and Social Sciences. Of these, 36 must be in the humanities (English, history, history and philosophy of science, humanities, music, philosophy, and visual culture) and 27 in the social sciences (anthropology, business economics and management, economics, law, political science, psychology, and social science). The remaining 36 may be drawn from humanities and social sciences, including HSS tutorial courses and 9 units of either Wr 1 or Wr 2. They may not include BEM 102. They may not include reading courses unless credit has been granted by petition to the humanities or social science faculty. Language courses may count toward the additional 36 unit requirement, with the exception of beginning, intermediate, and advanced classes in the student's native language. In general, no more than 18 units of first-year humanities may be counted toward the 99-unit requirement.

Entering first-year students are required to take two terms of first-year humanities; that is, cross-listed humanities courses numbered 60 or below in the *Catalog*. These classes introduce students to the basic issues and methods in the disciplines of English, history, philosophy, and visual culture. Successful completion of two terms of first-year humanities is a prerequisite for all humanities courses, except for foreign languages. It is *not* a prerequisite, however, for introductory social sciences. The first-year humanities classes may be taken in any two terms of the first year.

To encourage breadth, students will have to take their two first-year humanities courses in different disciplines, the disciplines being English, history, philosophy, and visual culture.

A student must take 18 units of advanced humanities courses as well. The classes that count as advanced humanities courses are those numbered 90 or above in English, history, history and philosophy of science, humanities, music, philosophy, and visual culture. Language courses do not count toward the advanced humanities requirement, except for courses that are cross-listed or taught concurrently with one of the listed subjects, such as humanities or visual culture. Courses used to fulfill the advanced humanities requirement must be taken for grades. Courses taken on a pass/fail

basis will not fulfill the requirement.

Since writing is an important method for developing and sharing ideas, all first-year humanities courses and other humanities courses numbered above 90, with the exception of some foreign languages and courses, require at least 4,000 words of composition. Instructors give extensive feedback on written work and help students improve their prose. As entering students may not be fully prepared for the writing in first-year humanities, all first-year and transfer students take a writing assessment before the beginning of the fall term. On the basis of this assessment, some students may be required to pass WR 2, 3, 4 and/or 50 before entering either first-year or advanced humanities classes.

Students are required to take two introductory social science courses and 18 units of related advanced undergraduate social science courses. Courses used to fulfill the advanced social science requirement must be taken for grades; courses taken on a pass/fail basis will not fulfill the requirement. The introductory social science courses must be drawn from the following list: either Ec 11, PS 12, or Psy 13. The 9 units of advanced undergraduate social science courses (numbered 100 and above), in fields following at least one of their introductory courses, must be taken as indicated here:

Introductory Course	**Following Course**
Ec 11	advanced economics or BEM (except BEM 102)
PS 12	advanced political science
Psy 13	advanced psychology

For instance, a student who has taken PS 12 and Ec 11 may use 9 units of advanced political science courses or 9 units of advanced economics courses.

Included in the 11 humanities and social science courses, students must take at least 3 writing-intensive courses and these must be taken on grades. The graded advanced humanities courses count towards this total. A student can select another course from advanced humanities or a social science course with writing content (specifically An/PS 127, BEM 109, Ec 105, Ec 129, Ec 130, Ec 140, PS 120, PS 123, or PS 141). These three writing-intensive courses should be spread out over the student's sophomore, junior, and senior years.

Physical Education Requirement

Before graduation, each undergraduate is required to successfully complete 9 units of physical education. This requirement may be satisfied entirely or in part by participation in intercollegiate athletics, or successful completion of physical education class course work. All grades are issued pass/fail. A maximum of 6 units per term may be applied toward graduation requirements, with the total not to exceed 36 units. Participation as a bona fide member of an intercollegiate team for the period covered by the sport in a given term satisfies the

requirement for that term.

A broad program of instruction is provided each term. Late registration is permitted during the first week of each term, provided there is space available and with permission of the instructor. Standards for evaluation of student performance will be clearly defined at the beginning of each course.

Scientific Writing Requirement

The following courses are suggested for each option, but the scientific writing requirement can be satisfied by taking an appropriate course offered by any division. The course used to satisfy this requirement must be taken on grades. All options also require a three-unit course in oral communication. Some options combine these two requirements into one course. At the discretion of the option, the scientific writing requirement can be satisfied by three units of additional work associated with a senior thesis, focused on effective written scientific communication.

Options	**Requirements**	
	Oral	*Written*
ACM, APh, CNS, CS, EE, EAS, IDS, ME, MS	SEC 10	one of SEC 11, SEC 12, or SEC 13
Ay	Ay 30	Ay 31
Bi, BE	Bi/BE 24	same
BEM, Ec, PS	En/Wr 83 or En/Wr 84	same
ChE	ChE 126	Ch/ChE 91
Ch	Ch 90	Ch/ChE 91
En, H, HPS, Pl	En/Wr 83 or En/Wr 84	same
GPS	See Option Requirements	ESE/Ge 21
Ma	Ma 10	Ma 11
Ph	Ph 70	same

TYPICAL FIRST-YEAR COURSE SCHEDULE, ALL OPTIONS

Differentiation into the various options begins in the second year.

		Units per term		
		1st	*2nd*	*3rd*
Ma 1 abc	First-Year Mathematics	9	9	9

Ph 1 abc	First-Year Physics	9	9	9
Ch 1 ab	General Chemistry	6	9	-
Bi 1 (any variant)	Principles of Biology	9	or 9	or 9
Ch 3 a	Fundamental Techniques of Experimental Chemistry[1]	6	or 6	or 6
CS 1 or CS 1 x	Introduction to Programming[2]	9	-	or 9
	Introductory courses in the humanities and social sciences. A wide choice of alternatives will be available to students; the registrar will announce the offerings for each term. Two terms are required.	9	and /or 9	and /or 9
	Introductory laboratory courses[3]	x	x	x
	Menu course,[4] First Year Seminar, or additional electives	x	x	x
PE	Physical education[5]	3	3	3

x—Except for the minimum laboratory unit requirement, the number of units chosen here is optional.

[1] *Students must take Ch 3 a or Ch 3 x in their first or sophomore year. This course is offered in each of the three terms.*

[2] *Students must take CS 1 or CS 1 x in their first or sophomore year. This course is offered in the Fall and Spring.*

[3] *The additional 6 units must be chosen from one of the following (or a more advanced laboratory course): APh/EE 9 (6 units), APh/EE 24 (9 units), Bi 10 (6 units), Ch 4 ab (9 units), Ch 8 (9 units), Ch/ChE 9 (9 units), EE/ME 7 (6 units), Ge 116 (9 units), ME 8 (6 units), ME 50 ab (12 units), Ph 3 (6 units), Ph 5 (9 units), Ph 8 bc (6 units).*

[4] *Students must take a menu course in their first or sophomore year. These courses are offered third quarter only. It is also possible to take one of these courses as an elective.*
Menu courses currently include Ay 1, EE 1, ESE 1, Ge 1, or IST 4.

[5] *Three terms (9 units) of PE are required for the B.S. degree. Students need not elect to take the required PE in the first year. It may be taken in any three terms before graduation.*

Integrated Core		*Units per term*		
		1st	*2nd*	*3rd*
Ma 1 a	Calculus of One Variable	9	-	-

IC/Ma 1 abc	Integrated Core Mathematics	6	9	3
IC/Ph 1 abc	Integrated Core Physics	9	9	9
IC/Ch 1 abc	Integrated Core General Chemistry with Lab	6	9	6
IC/Bi 1 abc	Integrated Core Biology	2	4	3
IC/Ge 1 abc	Integrated Core: Earth, Energy, and Climate	1	2	6
CS 1 or CS 1 x	Introduction to Programming[1]	9	-	-
IC/Hum 55 abc	Integrated Core Humanities	3	3	3
	A second introductory course in the humanities. A wide choice of alternatives will be available to students; the registrar will announce the offerings for each term.	-	-	9
IC 3	Integrated Core Additional Introductory laboratory	-	-	3
	Additional electives[2], including physical education[3], performing and visual arts, and frontiers courses	Up to 3	Up to 12	Up to 9

[1] IC students must take CS 1 or CS 1 x in their first year. Most students will take this course in the first term, but students placed into Wr 2 will take CS 1 in third term.

[2] In first and second terms, first-year students are limited to 45 academic units. Hence in first term, these additional electives may not be academic courses. In second term, up to 9 units of these additional electives may be academic courses.

[3] Three terms (9 units) of PE are required for the B.S. degree. Students need not elect to take the required PE in the first year. It may be taken in any three terms before graduation.

OTHER FIRST-YEAR COURSES

In addition to the required core classes described on the previous pages, first-year students are encouraged to participate in first-year seminar classes, frontier classes, research tutorials and other research opportunities.

First Year Seminars are a series of seminars in which 10 to 15 first-year students and a faculty member explore in depth an exciting topic in the lab, around a table, or in the field. These courses cover a wide range of topics, including earthquakes, gravitational waves, and the science of music. Instructors may allow sophomores, juniors, or seniors to enroll in these seminars after the conclusion of the pre-registration period for the upcoming term. See section on

First-Year Seminars for more information.

Caltech also offers a series of "frontier courses" that involve a weekly presentation by a faculty member on a topic of current research. These courses often meet at lunch time and serve pizza; hence, students refer to the courses as "pizza courses." The frontier courses are an opportunity for students to meet the Caltech faculty and to hear about state-of-the-art research projects for the summer or academic year. There are a total of 10 frontier courses offered for first-year students in biology, chemistry, mathematics, physics, geology and planetary sciences, engineering, computer science, chemical engineering, bioengineering, and electrical engineering.

Currently there are three "research tutorials" for first-year students: one in physics, one in biology, and one in chemistry. These tutorials have many of the same features as the first-year seminars. In physics, the research tutorial includes approximately seven first-year students and extends over three academic terms plus the summer. The purpose is to demonstrate how research opportunities arise, are evaluated, and are tested, and how the ideas that survive develop in larger projects. In biology and chemistry, the tutorials are offered in the winter and spring quarters and involve small group discussions on special areas or problems in biology, biotechnology, and chemistry.

More than 80 percent of Caltech students participate in research at some point in their academic career. Students may embark on research activities by registering for research credits with a faculty member, by working in a laboratory for pay during the summer or academic year, by completing a senior thesis, or by participating in Caltech's Summer Undergraduate Research Fellowship (SURF) program. The SURF program is described Undergraduate Programs and Research.

AEROSPACE MINOR (AE)

The aerospace minor is intended to supplement one of Caltech's undergraduate degrees and is designed for students who wish to broaden their knowledge beyond their normal major or who may wish to pursue a graduate program involving aerospace or aeronautical engineering. Students completing the aerospace minor requirements will have the phrase "minor in aerospace engineering" added to their transcripts.

Ae Minor Requirements

1. Complete Ae 105 abc.
2. Complete a second three-term 100-level Ae class, chosen from Ae 101 abc, 102 abc, 104 abc, 121 abc, Ae/Ge/ME 160 ab, or 27 units of selected Ae courses approved by the minor adviser. All Ae courses to be applied to fulfill the aerospace minor requirements must be taken for grades, and students must maintain an average grade of B or higher for all courses with no individual grade lower than a C. Courses that are used to satisfy the aerospace minor cannot be used to satisfy course requirements in the major options. Courses taken as part of the aerospace minor are counted toward the total 486-unit Institute

graduation requirements. A typical course sequence would be to take Ae 105 abc and the second Ae course in the senior year.

APPLIED AND COMPUTATIONAL MATHEMATICS OPTION (ACM)

Aims and Scope

The undergraduate option in applied and computational mathematics within the Computing & Mathematical Sciences department seeks to address the interests of those students who want to combine their basic studies in mathematics with considerable involvement in applications. This program is designed to give students a thorough training in fundamental computational and applied mathematics and to develop their research ability in a specific application field. The fields of application include a wide range of areas such as fluid mechanics, materials science, and mathematical biology, engineering applications, image processing, and mathematical finance. The training essential for future careers in applied mathematics in academia, national laboratories, or in industry is provided, especially when combined with graduate work, by successful completion of the requirements for an undergraduate degree in applied and computational mathematics. Complete programs will be worked out with faculty advisers.

ACM Double Majors

Students interested in simultaneously pursuing a degree in a second option must fulfill all the requirements of the ACM option. Classes cannot be counted towards both options unless specifically required by both. To enroll in the program, the student should meet and discuss their plans with the option representative. In general, approval is contingent on good academic performance by the student and demonstrated ability for handling the heavier course load.

ACM Option Requirements

1. Mathematical Fundamentals: Ma 2; Ma 3; Ma 6 ab or Ma 121 ab; Ma 6 c or CS 21; Ma 108 ab. Taking the analytical tracks of Ma 1 bc is strongly encouraged.
2. Programming Fundamentals: CS 1 or CS 1x; and basic numerical algorithms: ACM 11.
3. Communication Fundamentals: SEC 10; one of SEC 11-13.
4. Core Classes:
   a. Introductory Methods: ACM 95 ab.
   b. Linear Algebra: ACM 104 or ACM 107a.
   c. Probability: ACM 116 or CMS/ACM 117.
   d. Mathematical Methods: ACM 101 ab.
   e. Numerical Analysis: ACM 106 ab.
5. ACM Electives: In addition to all of the above requirements, 27 units of 100+ ACM courses approved by the adviser; up to 9 units of ACM 80 abc or ACM 81 abc can be counted towards this requirement with adviser approval.
6. Sequence: In addition to all of the above requirements, one 27-unit 100+ sequence in science engineering, or social sciences approved by the option representative.

7. Scientific Fundamentals: In addition to all of the above requirements, 18 units selected from BE/Bi 25, Bi 8, Bi 9, Ch 21 abc, Ch 41 abc, ME 11 abc, ME 12 abc, Ph 2 abc, or Ph 12 abc.
8. Passing grades must be obtained in a total of 486 units, including the courses listed above. Courses satisfying option requirements must be taken for grades (except when courses are only available P/F) and passed with a grade of C□ or higher.

Examples of choices for Requirement 5 by subject area include:

- Probability & Statistics: ACM 117, ACM 216, IDS/ACM 157, Ec/ACM 112, Ma/ACM 140
- Analysis & PDEs: ACM 107a, Ma/ACM 142 ab, AM/ACM 127, ACM 210
- Mathematical Modeling: ACM 154, ACM 180 ab

Requirement 6 is designed to give the ACM student some depth in an application area. Example sequences include, but are not limited to:

- Learning & Vision: CS156ab, CS 155, CS 159, EE 148, CNS 186, CNS 187, etc.
- Graphics: CS 171, CS 177, CS 179, etc.
- Robotics & Engineering: ME 115 ab, ME 134, EE 148, etc.
- Environmental Science: ESE 102, ESE 103, ESE 144, etc.
- Business & Finance: BEM 102, 103, 104, etc.
- Mechanics: Ae/AM/CE/ME 102abc, Ae/APh/CE/ME 101abc, Ae/Ge/ME 160ab, APh/MS/ME 105abc, etc.

ACM Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
First year				
CS 1	Intro. to Computer Programming	9	-	-
ACM 11	Intro. to Comput. Sci. & Eng.	-	-	6
Core	First year requirements	33	45	33
	Total	**42**	**45**	**39**
Second year				
Ma 2	Differential Equations	9	-	-
Ma 3	Intro. to Probability and Statistics	-	9	-

Ma 6 ab + Ma 6 c alt. CS 21 (9-18-0)	Intro. to Discrete Mathematics	9	9	9
ACM 104 (or 107a)	Appl. Linear Algebra	9	-	-
ACM 95 ab	Intro. Methods of Applied Math	-	12	12
Science Requirements	Option Requirement 7 Additional intro. lab	9	6	9
Electives	HSS or Option Requirements 5, 6	9	9	9
	Total	**45**	**45**	**39**
Third Year				
Ma 108 ab	Classical Analysis	9	9	-
ACM/IDS 101 ab	Methods of Applied Math	12	12	-
ACM/EE/IDS 116 (or 117)	Intro. To Probability Models	9	-	-
Electives	Option Requirements 5, 6 and HSS	9	18	36
SEC 10	Technical Seminar Presentations	-	3	-
One of SEC 11-13	Written Tech. Comm. in Engrng and Appl. Sci.	-	-	3
	Total	**39**	**42**	**39**
Fourth Year				
ACM 106 ab	Intro. Methods of Comput. Math	12	12	-
Electives	Option Requirements 5, 6 and HSS	27	27	36
	Total	**39**	**39**	**36**

APPLIED PHYSICS OPTION (APH)

Aims and Scope

The applied physics option is designed to extend knowledge of the principles of pure physics to the development of new technologies. Research in applied physics focuses primarily on problems of technological importance. The interdisciplinary nature of this option allows considerable flexibility in coursework, training and individual research interests to enhance maximum breadth and depth.

Current areas of specialization within applied physics span a wide range of topics such as Photonics including integrated microphotonic and nanophotonic devices, optical meta-materials, and optical approaches to quantum computation and communication; Solid-state materials and device work including nanostructured materials and devices, superconducting devices for quantum computation, wide bandgap semiconductors and heterostructures for optoelectronics, photovoltaics, novel memory devices, and spin-dependent transport; Biophysics including single-molecule-scale studies of the mechanics of DNA, proteins, and their assemblies; Plasma-physics including spheromak plasmas for fusion application, plasma processes occurring in the sun, and the dynamics of pure electron plasmas; Hydrodynamics, nonlinear dynamics and thermal behavior in small scale systems including symmetry breaking in soft condensed matter, micro/nanofluidic, optofluidic, and biofluidic devices, optical trapping in fluids, pattern formation and phase separation in nanoscale films and convection-diffusive phenomena in natural and mimetic systems.

APh Option Requirements

1. SEC 10 and one of SEC 11, SEC 12, or SEC 13. SEC 11-13 requirement can be satisfied by three units of additional work associated with the senior thesis (APh 78 or APh 79), or by taking Ph 70, En/Wr 84 or Bi/BE 24.
2. APh/EE 9, APh/EE 23, APh/EE 24. With option rep permission, one of these classes can be replaced with Ph 3, Ph 5, Ph 6, Ph 7 or Ch 6.
3. Ph 12 abc, APh/MS/ME 105 ab [Ph 127 ab], Ph 106 abc, and Ph 125 ab [Ch 125 ab]
4. Ma 2, Ma 3, and ACM 95/100 ab.
5. Either APh 78 abc or APh 79 abc, or three terms of APh 123, APh 109, APh 119, Ae/APh 104 bc or Ph 77 ab. Any substitutions or additions require prior approval of the option representative.
6. Four advanced APh courses numbered over 100 from Ae/APh/CE/ME 101 abc, Ae/Aph 104 abc, APh/MS/ME 105 c, APh/Ph 112, APh 114 abc, Ph/APh/EE/BE 118 ab, Ph/APh/EE 118 c, EE/APh 120, Ph/APh 137 ab, APh/Ph 138 ab, APh/MS 141, EE/APh 149, APh/Ph/MS 152, APh/Ph/Ae/MS 153, APh/EE 130/131/132, APh 156 abc, EE/APh 158, APh/EE 190 abc, BE/Bi/APh 161, MS/APh 162, MS/APh 171, EE/APh 180, APh/EE 183, Ae/ME/APh 218, Ph/APh 223 ab, APh/MS 256. In case the courses are offered as a two or three class sequence, the entire sequence should be taken if offered. Note that APh 100 and APh 200 do not satisfy this requirement. Any substitutions or additions require prior approval of the option representative.
7. Passing grades must be earned in a total of 486 units, including the courses listed above. No course in fulfillment of option requirements may be taken on a pass/fail basis.
8. Any student whose grade-point average is less than 1.9 at the end of the academic year in the subjects listed above may be refused permission to continue work in this option.

APh Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
ACM 95/100 ab	Intro. Methods of Applied Math.	-	12	12
APh/EE 23	Demonstration Lectures in Optics	-	9	-
APh/EE 24	Introductory Modern Optics Laboratory	-	-	9
Ma 2	Differential Equations	9	-	-
Ma 3	Intro. to Probability and Statistics	-	9	-
Ph 12 abc	Waves, Quantum Mechanics and Statistical Physics	9	9	9
	HSS Electives	9	-	9
	Laboratory Electives	6	9	-
	Other Electives	9	-	9
	Total	**42**	**48**	**48**
Third Year				
APh/MS/ME 105 ab	States of Matter	9	9	-
APh 110 ab	Topics in Applied Physics	2	2	-
Ph 106 abc	Topics in Classical Physics	9	9	9
Ph 125 ab	Quantum Mechanics	9	9	-
	HSS Electives	9	9	9
	Other Electives	9	9	27
	Total	**47**	**47**	**45**
Fourth Year				
	Senior Thesis, Experimental or Theoretical, or Laboratory in Applied Physics	9	9	9
	Advanced Electives	9	9	9
	HSS Electives	9	9	9

	Other Electives including APh 100	18	18	18
	Total	**45**	**45**	**45**

Suggested Electives
Students are encouraged to obtain a well-rounded course of study pursuant to the B.S. degree in applied physics. The option representative and/or undergraduate adviser will gladly assist students in choosing appropriate elective courses. Students ultimately interested in pursuing an advanced degree in applied physics or related fields are encouraged to complete a senior thesis project through APh 78 or APh 79.

ASTROPHYSICS OPTION AND MINOR (AY)

Aims and Scope
With the goal of understanding the physical processes that govern the universe, its constituents, and their origins and evolution, astronomy uses the apparatus and methodology of physics to gather and interpret data. Theoretical work and technology development round out astrophysics. In what follows, we use the terms “astronomy” and “astrophysics” interchangeably. The astrophysics option is designed to give the student an understanding of the basic facts and concepts of astronomy today, to stimulate their interest in research, and to provide a basis for graduate work in astronomy/astrophysics.

Undergraduate Information
Students petitioning to double-major in Astrophysics and Physics must present a plan that has a minimum of 92 units that are solely counted as satisfying the Ay requirements, and a minimum of 92 units that are solely counted as satisfying the Ph requirements.

Attention is called to the fact that any student whose grade-point average is less than 1.9 at the end of an academic year in the subjects listed in the Division of Physics, Mathematics and Astronomy may, at the discretion of their department, be refused permission to continue the work in this option.

Ay Option Requirements
1. Ay 20, 21, 101, 102, 30 or one term of Ay 141, Ay 31, Ma 2, Ma 3, Ph 2 abc or Ph 12 abc, Ph 125 ab, Ph 106 ab, Ph 106 c or Ph 107.
2. Any three of Ph 3 or Ph 8bc, Ph 5, Ph 6, Ph 7, Ph 77, or Ay 105. APh 23 plus APh 24 or 123 may be substituted for one of these labs.
3. 63 additional units of Ay or Ph courses. Ph 127 a, Ph 136 bc and one of Ph 21, Ph 22, Ph 121 abc are strongly recommended.
4. 27 additional units of science or engineering electives, of which 18 must be outside the Division of Physics, Mathematics and Astronomy. Core classes or other introductory-level courses do

not count toward fulfillment of this requirement.

5. Passing grades must be earned in a total of 486 units, including the courses listed above. Courses satisfying requirements 1, 2, and 3 must be taken for grades unless they are pass/fail only.

Ay Example Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
Ph 12 abc or Ph 2 abc	Sophomore Physics	9	9	9
Ma 2, Ma 3	Sophomore Mathematics	9	9	-
Ay 20	Basic Astronomy and the Galaxy	9	-	-
Ay 21	Galaxies and Cosmology	-	9	-
Ay 30	Intro. to Modern Research	3	-	-
Ph 3[1] or 5[1]	Physics Laboratory	9	-	-
ACM 95 ab[2]	Intro. Methods of App. Math.	-	12	12
Ph 21 or 22[3]	Computational Tools	-	-	6
	HSS Electives	9	9	18
	Total	**48**	**48**	**45**
Third Year				
Ph 125 abc[4]	Quantum Mechanics	9	9	9
Ph 106 abc	Topics in Classical Physics	9	9	9
Ay 101	The Physics of Stars	9	-	-
Ay 102	Physics of the Interstellar Medium	-	9	-
Ay 104[3]	High Energy Astrophysics	-	-	9
Ph 127 a[3]	Statistical Physics	9	-	-
Ph 6[1], 7[1], or APh 23/24[1]	Physics Laboratory	-	9	9
	Other Electives	-	9	-
	HSS Electives	9	-	9
	Total	**45**	**45**	**45**
Fourth Year				

Ay 31	Written Communication	-	-	3
Ay 105[1]	Astronomy Instrumentation Lab	-	-	9
	Ay/Ph Electives	9	9	9
Ay 78	Senior Thesis	9	9	9
Ph 121[3] or Ay 117	Computational Analysis	-	6	-
Ay 141 b[3]	Research Conference in Astronomy	-	3	-
	Other Electives	18	9	9
	HSS Electives	9	9	9
	Total	**45**	**45**	**48**

[1] Choose among laboratory classes to satisfy Option Requirement 2.
[2] While ACM 95 is a popular choice for Option Requirement 4, other courses in ACM or options such as CS, APh, EE, and Ge may also be used.
[3] Strongly recommended courses for Option Requirement 3. Other courses may be substituted.
[4] Phys 125c is recommended and can be counted towards Option Requirement 3.

The sequence Ay 20, 21 constitutes a solid introduction to modern astrophysics, with more advanced courses (Ay 101, 102, plus Ay electives) taken in the junior and senior years. The course schedule above is an example leading to excellent preparation for graduate study, but it is also possible to fulfill the option requirements with a more diverse set of electives across options, and even to take Ay 20, 21 junior year and Ay 101, 102 senior year. In either scenario, it is desirable for a student to gain as broad a background as possible in related fields of science and engineering. An ability to present one's work is vital to a successful career in any field. The oral communications requirement can be satisfied by presenting during a term of Ay 141, or with Ay 30. Ay 31 satisfies the written communication requirement.

Students are encouraged (but not required) to undertake research leading to a senior thesis; credit for this work is provided through Ay 78 with the process and requirements fully described there.
Non-thesis research credits may be earned through Ay 142 with a maximum of 9 units per term. Elective credit can be given for no more than 27 units of Ay 142.

Computational skills may be acquired through e.g. ACM 11, ACM 106, CS 2, CS 11, CS 21, CS 38, CS 121, CMS 155, Ph 20, Ph 21, Ph 121.

Students are strongly advised to take advanced mathematical methods in ACM95 and Ph 129, and an advanced statistical physics

or thermodynamics course such as Ph 127.

Suggested Electives

The student may elect any course offered in any division in a given term, provided that they have has the necessary prerequisites for that course. The following courses are useful to work in various fields of astronomy and astrophysics: ACM 95, ACM 106, ACM 112, APh 17, APh/EE 23/24, APh/EE 117, APh 123, Ay 104, Ay 105, Ay 107, Ay 117, Ay 121–127, Ch 125 ab, EE 45, EE/Ae 157, Ge/Ay 11 c, Ge 103, Ge/Ch 128, Ge 131, Ge/Ay 132, 133, 137, Ge 141, Ma 4, Ma 112, ME 11, ME 12, Ph 20–22, Ph 77, 101, 121, 127, 129, 136, 137, 199, 236 (this is not necessarily a complete list).

Ay Option Minor

The Ay minor is expected to appeal to student interest in the field of astronomy that arises from overlap, not only with the most traditional area of physics, but with more recent and rapidly developing intersections of astronomy. Recent Ay minors have had major options in computer science, engineering, chemistry, planetary science, and mathematics.

Ay minor coursework is designed to prepare the capable student to undertake cross-disciplinary research involving astronomy. A firm basis for this is established with sophomore level physics and astronomy requirements. Junior year courses sample from among the Ay major requirements and electives. Both traditional theory courses and more hands-on practical training courses are available, with one course of each type recommended for breadth. Senior year features research and written presentation of the research, with additional electives encouraged.

Courses taken in the minor option must be taken for grades (no P/F), except for Ay 142 which is offered as P/F only. Courses 100 and above can not be used to also satisfy requirements in the student's major option.

Ay Option Minor Requirements

1. Basis in physics: either Ph 2ab or Ph12 ab (18 units)
2. Introductory Astronomy: any two of Ge/Ay 11c, Ay 20, or Ay 21 (18 units)
3. In-depth Astrophysics, Instrumentation, and Data: any two among: Ay101, Ay 102, Ay 104, Ge/Ay 133, Ay 105, Ay/Ge 107, Ay 122; substitution of other advanced courses is permitted by petition to the Ay option representative (18 units)
4. Research: both Ay 142 (9 units) and Ay 144 (3 units) = (12 units)

Total units required: 66

Other courses of interest to students seeking Ay minor competency include Ay 119, Ay 198, Ay 141, Ph 2c/12c, Ph 101, EE 40, APh/EE 23. These do not contribute to credit for the minor, however.

Course selection should be done in consultation with the Ay option representative, who can advise on an appropriate curriculum for a given student's goals.

As a complement to the required Ay 142 enrollment, SURF research with the relevant Ay, Ph, or Pl.Sc. faculty member is encouraged.

BIOENGINEERING OPTION (BE)

Aims and Scope

The undergraduate bioengineering option provides a foundation for graduate studies and career paths that require the application of engineering principles to the design, analysis, construction, and manipulation of biological systems, and in the discovery and application of new engineering principles inspired by the properties of biological systems. By graduation, students are expected to have learned basic laboratory and engineering methods used in a broad range of bioengineering sub-disciplines.

Students will also have learned quantitative and analytic skills vital to experiments and system designs. Graduating students are expected to be able to critically evaluate and understand bioengineering literature, and be able to work in a team and communicate effectively.

To accomplish these goals, students are expected to complete a series of required courses designed to introduce them to a representative range of bioengineering sub-disciplines, provide them with a solid quantitative analysis foundation, and provide them with opportunities to work in teams through a number of project-oriented courses. Students will receive instruction in scientific communications through Bi/BE 24.

Undergraduate research is encouraged both during the academic year and through participation in summer research programs.

Students should present a plan for satisfying all degree requirements to their academic adviser by the end of the third term of the second year.

Students with a grade-point average lower than 1.9 will not be allowed to continue in the option except with special permission from the option representative.

BE Option Requirements

1. BE/Bi 103 a or IDS/ACM/CS 157, BE 150 or BE/CS/CNS/Bi 191 a, BE/Bi/APh 161, BE/ChE 163.
2. Experimental methods: Bi 1x; one of BE/EE/MedE 189 a or BE 107; one of ChE/Ch/BE 130 or BE/CS 196 a. Students are strongly encouraged to enroll in Bi 1x as first-year students; Bi 1x must be completed by the sophomore year. The Bi 1x requirement is waived for students who complete integrated core. Nine total units of BE 98 and BE 99 may be used in place of one of these courses (except Bi 1x) with the approval of the undergraduate option representative to ensure that the student's research project provides comparable experimental laboratory experience. BE 98 and BE 99 units used to satisfy this requirement may not also be counted toward the elective requirement.

3. Biology, chemistry, and physics: two terms out of three from Ph 2 abc (Ch 21 a may be used in place of Ph 2 b and Ch 21 c may be used in place of Ph 2 c); Bi 8; Bi 9; BE/Bi 25; Ch 41 a; Ch/Bi 110 a. One advanced biology course of at least 9 units selected from Ch/Bi 111, Bi 114, Bi 117, Bi/BE 119, Bi 122, Bi 145 ab, NB/Bi/CNS 150, BE 150, Bi/BE/CS 183, or approved by the undergraduate option representative.
4. Mathematical and computational methods: ACM 95 ab; Ma 2; Ma 3; one course from ChE 105, CDS 110, or ACM 116; 9 units selected from CS 1, CS 2, CS 3, CS 21, CS 24, and CS 38.
5. 36 units of BE electives. These may include BE 98 and BE 99 (up to 12 units), any BE course numbered 100 or above except BE/Bi/CNS/NB 197, any of the BE-approved electives listed below, or any relevant course approved by the option representative. Additionally, courses listed in requirements 1-3 that are not used to fulfill those requirements may be counted as electives.
6. Communication: Bi/BE 24.
7. Courses satisfying option requirements must be taken for grades (except when courses are only available P/F). Passing grades must be earned in a total of 486 units.

BE-Approved Electives

Biology: Bi/Ge/ESE 105, NB/Bi/CNS162, Bi 180,Bi 190.

Biodevices: EE 112, EE 113, EE/MedE 114 ab, APh/EE 9, EE 45, EE 111, EE 151, CS/CNS/EE 156 a.

Biomaterials: ChE/Ch/Ms 113, MS/ME/MedE 116

Biomechanics: ME 12 abc, ME 14, Ae/APh/CE/ME 101 abc, Ae/AM/CE/ME 102 abc, Ae/APh 104 abc, ME 11 abc, ChE 103 abc.

Computational biology: CMS/CS/CNS/EE/IDS 155, CS/CNS/EE 156 a

Synthetic biology: Ch 41 bc, ChE/Ch 148, ChE/Ch 164, ChE/Ch 165, APh/MS/ME 105 abc.

BE Typical Course Schedule

(Specific courses are representative and may be substituted per option requirements.) Students planning on pursuing graduate study should have a strong emphasis on research in their schedule and are advised to start their sophomore year and continue throughout their study.

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
Ma 2, Ma 3	Sophomore Mathematics	9	9	-
Ph 2 ac	Sophomore Physics	9	-	9
Ch 41 a	Organic Chemistry	9	-	-

ACM 95 ab	Introductory Methods of Applied Mathematics for the Physical Sciences	-	12	12
Bi 8, Bi 9	Molecular and Cell Biology	-	9	9
BE/Bi 25	Biophysical Chemistry	-	9	-
BE 98	Undergraduate Research in Bioengineering	-	-	6
	HSS electives	9	9	9
	Total	**36**	**48**	**45**
Third Year				
Ch/Bi 110 a	Introduction to Biochemistry	12	-	-
BE/ChE 163	Introduction to Biomolecular Engineering	12	-	-
BE/Bi 103 a	Introduction to Data Analysis in the Biological Sciences	9	-	-
BE/Bi/APh 161	Physical Biology of the Cell	-	12	-
BE/CS 196 a	Design and Construction of Programmable Molecular Systems	-	12	-
	Advanced Biology Elective	-	-	9
Bi/BE 24	Scientific Communication for Biological Scientists and Engineers	-	-	6
BE 98	Undergraduate Research in Bioengineering	9	9	9
	HSS Electives	-	9	18
	Total	**42**	**42**	**42**
Fourth Year				
BE/EE/MedE 189 a	Design and Construction of Biodevices	12	-	-
BE 150	Biological Circuit Design	-	-	9
ChE 105	Dynamics and Control of Chemical Systems	-	-	9
	BE Electives	9	9	9
BE 99	Senior Thesis in Bioenginerring	9	9	9

	HSS Electives	9	18	-
	Total	**39**	**36**	**36**

BIOLOGY OPTION AND MINOR (BI)

Aims and Scope

The undergraduate option in biology is designed to build on a solid foundation in mathematics and physical science by providing an introduction to the basic facts, concepts, problems, and methodologies of biological science. The option serves as a basis for graduate study in any field of biology or for admission to the study of medicine. Instruction is offered in the form of participation in the ongoing research programs of the division, as well as in formal course work. Course work emphasizes the more general and fundamental properties of living organisms, and areas of current research interest, rather than the traditional distinct fields within the life sciences.

The division encourages undergraduate participation in its research program and believes that research participation should be a part of each student's program of study. Students may elect to prepare an undergraduate thesis (Bi 90). Research opportunities may be arranged with individual faculty members, or guidance may be obtained from a student's individual faculty adviser in the division or from the biology undergraduate student adviser.

The requirements listed below for the biology option are minimal requirements. An adequate preparation for graduate work in biology will normally include additional elective research or course work in biology and/or advanced course work in other sciences or in mathematics. Flexibility to accommodate varied individual scientific interests, within the broad scope of biology, is achieved through the provision of elective courses, arrangements for individual research (Bi 22), and tutorial instruction (Bi 23). In addition, arrangements may be made to take courses at neighboring institutions in fields of biology that are not represented in our curriculum.

Premedical Program

The undergraduate course for premedical students is essentially the same as that for biology students and is intended as a basis for later careers in research as well as in the practice of medicine. It differs in some respects from premedical curricula of other schools; however, it has been quite generally accepted as satisfying admission requirements of medical schools.

It is recommended that all students contemplating application to medical school consult with the premed adviser at Careers, Advising, and Experiential Learning or Professor Mitchell Guttman in the Division of Biology and Biological Engineering.

Bi Option Requirements

The following required courses must all be taken on grades, with the exception of Bi 8 if taken as a first-year student and Bi 22. First-year students taking Bi 8 must maintain shadow grades that indicate satisfactory progress.

1. Bi 8, Bi 9, Bi 117, Bi 122, NB/Bi/CNS 150, and Ch 41 abc.
2. Ma 2, Ma 3, and any two terms of Ph 2 abc. BE/Bi 25 can be taken in place of Ph 2 c. This requirement can also be satisfied in part by successfully taking a "reasonable" replacement for any of these required courses. A "reasonable" replacement will be defined by: (1) Equally or more advanced quantitative coursework, e.g. Ch 21 a for Ph 2 b, Ch 21 c for Ph 2 c and; (2) Essentially similar scope of subject matter as the course replaced. The Biology option representative will be empowered to make this determination with aid of an advisory list which can be updated as relevant new courses are developed inside and outside of biology.
3. One advanced laboratory course (100- or 200-level), or Bi 21 with presentation, or three terms of undergraduate thesis (Bi 90 abc).
4. Two courses chosen from Ch/Bi 110 a, 110 b, 111, and/or BMB/Bi/Ch 170, 173 or Ch 145.
5. Scientific writing requirement met by taking Bi/BE 24 (six units), or by taking any other writing course such as En/Wr 84 (nine units) plus oral presentation at SURF Seminar Day or equivalent, with option representative approval.
6. A minimum of 8 courses of biology electives must be taken. To count as a biology elective, a course must satisfy the following:
    a. The course is not used to satisfy requirement 1-5.
    b. 100-level or above.
    c. The course must be a biology or a bioengineering course.
    d. At least two elective courses must be nine units each, and must be taken for grades.
    e. A minimum total of four elective courses must be taken for grades.
7. Exceptions are as follows:
    a. Substantial lab research for credit (Bi 22) beyond the 12-unit minimum can be counted among the electives.
    b. Courses from other options with significant relevance to biology may be used as electives with permission from the biology option representative.
8. A minimum total of 170 units of biology must be taken and passed. Any Bi 1 course, Bi 2, Bi 10, and BE/Bi/CNS/NB 197 cannot be counted toward this total. Bioengineering courses used for electives can be counted toward this total.
9. Passing grades must be earned in a total of 486 units, including the courses listed above.

Planning the Biology Course Schedule

- Most students interested in biology elect to take Bi 8 and Bi 9 in their first year, to open access to the widest range of biology electives.
- Bi 10 or Bi 1x is not required for the biology option but is commonly taken by biology students to meet the Institute introductory laboratory requirement.
- Prerequisites listed for individual biology courses are advisory, not compulsory. They indicate the kind of background that is assumed for the work level of the course. They may be waived if the instructor gives explicit permission.
- BE/Bi 25 is strongly recommended for students interested in postgraduate work in biology, as physical chemistry is required by most graduate programs.
- Additional courses of potential interest to biology majors include Ge 11 b, BE 159, BE/Bi/APh 161, BE/ChE 163, BMB/Ch 178 and advanced geobiology courses.
- Undergraduates are generally welcome to take 200-level courses with the instructor's permission or strong preparation, unless otherwise indicated.

Bi Typical Course Schedule (Required courses and representative examples of electives)

		Units per term		
		1st	*2nd*	*3rd*
Second year				
Ma 2, Ma 3	Sophomore Mathematics	9	9	-
Ph 2 ac	Sophomore Physics	9	-	9
Ch 41 abc	Organic Chemistry	9	9	9
Bi 8, Bi 9	Molecular and Cell Biology*	-	9	9
Bi 10	Introductory Biology Laboratory*	-	-	6
Bi 22	Undergraduate Research in Biology	6	6	6
	HSS Elective	9	9	9
	Total	**42**	**42**	**48**
Third year				
Bi 122	Genetics	9	-	-
Bi 117	Developmental Biology	-	12	-
NB/Bi/CNS/ 150	Introduction to Neuroscience	-	-	10

Bi/BE 24	Scientific Communication for Biological Scientists and Engineers	-	-	6
Bi 22	Undergraduate Research in Biology	9	9	9
Ch/Bi 110 a	Introduction to Biochemistry	12	-	-
Ch/Bi 111	Biochemistry of Gene Expression	-	12	-
	Bi Elective	-	-	9
	HSS Electives	9	9	9
	Physical Education	3	-	-
	Total	**42**	**42**	**43**
Fourth year				
	Bi Electives	9	18	18
Bi 90 abc	Senior Thesis in Biology	18	18	18
	HSS Electives	9	9	-
	Physical Education	3	-	3
	Total	**39**	**45**	**39**

Biology Minor Requirements
The biology minor is intended to supplement one of Caltech's undergraduate degrees. It is designed for students who wish to broaden their studies beyond their major to include biology. Students completing the biology minor requirements will have the phrase "minor in biology" added to their transcripts.

1. Biology fundamentals. Bi 8 and Bi 9.
2. Intermediate Biology. Any two of the following classes: Bi 122; Bi 117; and NB/Bi/CNS 150; and Ch 41 a.
3. Advanced Biology. 36 units of advanced biology electives (100- or 200-level) that are not applied to the above requirements and are not simultaneously used for fulfilling a requirement of the student's major option, approved by their assigned biology adviser or the option representative.

BUSINESS, ECONOMICS, AND MANAGEMENT OPTION (BEM)

Aims and Scope

The goal of the business, economics, and management (BEM) option is to provide students with the analytical tools to operate successfully in a modern business environment and to prepare students interested in pursuing graduate studies in related fields. The emphasis is on entrepreneurship, finance, and strategy, in free-market, competitive, and strategic situations. Today's business environment is complex, and therefore required courses in this option are highly analytical. Students often pair the BEM option as a double major with a science or engineering option. The BEM option also serves as a standalone major for students interested in careers in the financial industry, consulting, or entrepreneurial ventures. Expected learning outcomes from completing the BEM option include:

- a strong background in economic theory and econometrics;
- an understanding of the theoretical and practical aspects of finance, risk management, business strategy;
- an ability to analyze business problems using qualitative and quantitative methods;
- an ability to analyze financial and business data;
- the skills necessary to pursue graduate education in finance, economics, and related fields;
- an ability to write and communicate effectively; and
- an understanding of the broader impacts of business and management on society in general.

Note: The official source on requirements for graduation is the Caltech catalog from the year in which a student began studies at Caltech. Please see the catalog online, from this and previous years, for information regarding the applicable option requirements.

BEM Option Requirements

It is highly recommended to take a statistics/econometrics course, as well as BEM 102 and BEM 103 before other BEM courses.

1. Ec 11, Ec 122, Ma 3 or ACM/EE/IDS 116, and PS/Ec 172.
2. BEM 102 and BEM 103.
3. Three BEM courses numbered 104 or higher. At least two of those have to be from BEM 104 to BEM 112, and only one of BEM 104 and BEM 114 may be taken.
4. Writing/oral presentation courses: a scientific writing requirement course, and a three-unit course in oral communication, offered by any division (some options combine these two requirements into one course, that can be taken to satisfy this requirement), or En/Wr 84. The course used to satisfy this requirement must be taken on grades.
5. Five courses, to be chosen from the menu (up to two of those may be taken pass/fail; note that some options do not allow

double-counting of courses used in another option): any BEM courses (excluding the ones listed under 2 and 3 above, and only one of BEM 104 and BEM 114 may be taken), ACM 113, ACM/EE/IDS 116 (if not taken under requirement 1) CS/Ec 149, E 102, Ec/ACM/CS 112, Ec courses numbered 105 or higher (if not taken under requirement 1), Ma 112a, Ma/ACM/IDS 140ab and PS/Ec/IDS 126. No more than one from these three: CMS/CS/CNS/EE/IDS 155, CS/CNS/EE 156a and IDS/ACM/CS 157. Other courses with permission of BEM option representative. At least two of these five courses have to be BEM, Ec, PS or SS courses.

6. 45 additional units of science (including economics, political science, psychology, social science), mathematics, and engineering courses; this requirement cannot be satisfied by courses listed as satisfying the introductory laboratory requirement or by any course with a number less than 100 (may be taken pass/fail).
7. Passing grades must be earned in a total of 486 units, including all courses used to satisfy the above requirements

BEM Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
Ma 2 & Ma 3	Sophomore Mathematics	9	9	-
Menu Course		-	-	9
Ec 11	Introduction to Economics	9	-	-
BEM 102	Introduction toAccounting	-	-	9
BEM 103	Introduction to Finance	-	9	-
PS/Ec 172	Game Theory	-	9	-
	Electives [1]	18	18	27
	Total	**36**	**45**	**45**
Third Year				
BEM 104	Investments	-	9	-
BEM 105	Options	9	-	-
Ec 122	Econometrics	9	-	-
	Electives [1]	27	36	45
	Total	**45**	**45**	**45**

Fourth Year				
En/Wr 84	(or 3 unit course in oral communications and a scientific writing requirement course	-	-	9
BEM110	Venture Capital	-	9	-
	Electives	45	36	36
	Total	**45**	**45**	**45**

[1] *See option requirements 4 and 5*

CHEMICAL ENGINEERING OPTION AND MINOR (CHE)

Aims and Scope

Caltech's Chemical Engineering option prepares its students for the future, whether that be furthering research and development in industry, or continuing their studies at the graduate level. The option's breadth enables its students to make an impact in a variety of fields, such as: researching sustainable technologies (energy efficiency, pollution management, climate mitigation, biofuels); inventing novel biotechnologies (enzyme engineering, cell culturing, pharmaceuticals); and developing processes for organic (polymers, films, fuels, pharmaceuticals) and inorganic (semiconductors, ceramics) products.

This is accomplished through a mixture of interdisciplinary classes that expose students to: most fields of science (chemistry, physics, mathematics, biology); core chemical engineering principles; and an area of specialization. The inherently computational nature of chemical engineering shines through courses' active use of computational software such as Python, Matlab, Mathematica and COMSOL for modelling and data analysis. At the same time, classes and independent projects also focus on systematic analysis and problem solving, incorporating social, economic, environmental, and technical constraints to tackle the open-ended challenges of today and tomorrow with new and creative solutions. Undergraduate research is emphasized, and students are encouraged, even in the first year, to participate in research with faculty.

First-year students normally take core courses in mathematics, physics, chemistry, and biology (Ma 1 abc, Ph 1 abc, Ch1 ab, Bi 1), as well as general chemistry lab (Ch3a or Ch 3x). First-year students may take ChE 15 or wait until their second year. In their second year, students take advanced courses in math and science, including differential equations (Ma 2), applied math (ACM 95 ab), wave physics (Ph 2a), organic chemistry (Ch 41 ab), and organic chemistry lab (Ch/ChE 9).

The option's curriculum begins in students' second year and continues through their third year with fundamental studies in heat transfer, fluid mechanics, mass transfer, thermodynamics, reactor design, and chemical kinetics. While still building a common

foundational toolkit, third-year students also begin to specialize in one of five tracks: biomolecular, sustainability, process, materials, computational. Students learn and use design principles in multiple lab courses that entail hands-on, open-ended projects relevant to current research so students can innovatively apply chemical engineering concepts. Students may also pursue an undergraduate thesis to explore research topics under the mentorship of professor - proposing a research plan, applying relevant lab techniques, and presenting results through project reports, oral presentation, and written thesis. More information about the option and track requirements can be found on: https://tinyurl.com/2kxfnnva.

Attention is called to the fact that any student whose gradepoint average is less than 1.9 at the end of an academic year in the subjects listed under the Division of Chemistry and Chemical Engineering may, at the discretion of the faculty in this division, be refused permission to continue the work in this option.

ChE Option Requirements

1. Ma 2, Ph 2 a, Ch/ChE 9, ChE 15, Ch 21 ab [†] , Ch 41 ab, ChE 62, ChE 63 ab, Ch/ChE 91 (or En/Wr 84), ACM 95 ab, ChE 101, ChE 103 abc, ChE 105, ChE 126, one of [ACM/EE/IDS 116, BE/Bi 103a, ChE/Ch 137] [a] and one of [Ec 111, Ec 117, BEM 102, or BEM 103, BEM 104, BEM 119] [1] .
2. Completion of a track (biomolecular, sustainability, process systems, materials or computational), each consisting of at least 63 units of science or engineering courses. Students should inform the undergraduate option representative of their track choice by the beginning of the spring quarter of the sophomore year by providing a planned schedule for completion of all degree requirements. Requirements for the tracks are as follows.
    a. Biomolecular track: BE/ChE 163, [Ch/Bi 110a or Ch/Bi 110b], [ChE 130 or ChE 90 c], and additional units of bioengineering or biochemical engineering electives or approved related courses. [3,4]
    b. Sustainability track: two of [ChE/ESE/ME/MS 111, ESE 101, ESE 102, ESE 103], one of [ChE 128 ChE 90 c, Ge 114 a], and additional units of 100 level ESE electives, 100 level EST electives or approved related courses. [3,4,5]
    c. Process systems track: ChE 118, ChE 120, [ChE 128 or ChE 90 c], and additional units of engineering electives, courses from the other tracks, or approved related courses. [3]
    d. Materials track: [ChE 128 or ChE 90 c]; at least one course on materials synthesis or processing selected from [Ch 102, Ch 117, Ch/ChE 147 [2] , ChE/Ch/MS 113, ChE 115 [2] , MS 133 or an approved substitute]; at least one course on the physical basis of structure and properties selected from [Ch 120 ab, ChE/Ch 148 [2] , MS 115, MS/APh 122 [2] , MS 131, MS 132 or an approved substitute]; and additional units of 100 level ChE electives, 100 level MS electives, 100 level APh electives or approved related courses. [3,4]

e. Computational track: ACM/IDS 104, ChE/Ch 137, at least one course sequence from [Ch 121 ab; BE/ChE 163 & BE/CS/CNS/Bi 191a; ESE 101 & ESE 136; Ae 232 ab; or ChE 90 abc], and additional units from ChE/Ch 139 or approved courses in IDS, ACM, CS or related options. [3]

For students electing to complete two tracks, no course can be used to fulfill the requirements of more than one track.

1. Passing grades must be earned in all courses required by the Institute and the option. None of the courses satisfying option requirements may be taken pass/fail (except when courses are only available P/F)
2. Passing grades must be earned in a total of 486 units, including courses listed above.

† *Ph 12 b may substitute for Ch 21 a.*

[1] The 9 units of Ec 11, Ec 117, BEM 103, BEM 104 or BEM 119 partially satisfy the Institute requirements in humanities and social sciences. BEM 102 does NOT count for Institute core social science course.

[2] Course is not typically offered every academic year. Typically offered in alternate years.

[3] No more than 18 units of [ChE 90ab, ChE 80 or BE 98] may count as track electives.

[4] ChE 118 and/or ChE 120 may be elected provided the design project undertaken contains a significant component relevant to the track.

[5] students in the sustainability track are encouraged to take one policy-related course [BEM/Ec/ESE 119 or ME/EE/EST 117] as a track elective.

ChE Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
Ma 2	Ordinary Differential Equations	9	-	-
Ph 2 a	Sophomore Physics: Waves	9	-	-
Ch/ChE 9	Chemical Synthesis and Characterization for Chemical Engineering	-	-	9
ChE 15	Introduction to Chemical Engineering Computation	-	9	-
Ch 41 ab	Organic Chemistry	9	9	-
ChE 62	Separation Processes	-	-	9

ChE 63 ab	Chemical Engineering Thermodynamics	9	9	-
ACM 95 ab	Intro. Methods of Applied Math.	-	12	12
PE	Physical Education	-	-	3
	HSS electives	9	9	9
	Total	**45**	**48**	**42**
Third Year				
ChE 103 abc	Transport Phenomena	9	9	9
ChE 101	Chemical Reaction Engineering	-	9	-
ChE 105	Dynamics and Control of Chemical Systems	-	-	9
Ch/ChE 91	Scientific Writing	3	-	-
	ChE track electives[1]	9	9	9
Ec 11 (or BEM 103 2nd term)		9	-	-
	Free Electives	9	-	-
	HSS electives	-	9	9
	Total	**39**	**36**	**36**
Fourth Year				
ChE 126	Chemical Engineering Lab	9	-	-
	ChE track electives[1]	18	9	18
Ch 21 ab	Physical Chemistry	9	9	-
	Free Electives	-	9	9
	HSS electives	9	9	9
	Total	**45**	**36**	**36**

[1] *See option requirements.*

ChE Minor Requirements

The chemical engineering minor is intended to supplement one of Caltech's undergraduate degrees. It is designed for students who wish to broaden their studies beyond their major to include chemical engineering. Students completing the chemical engineering minor requirements will have the phase "minor in chemical engineering" added to their transcripts. The chemical engineering minor

requirements include:

1. ChE Core: ChE 63A, ChE 103a, ChE 103b, ChE 101
2. If ACM 95ab is not required for your major option, fulfill (2a). If ACM 95ab is required for your major option, fulfill (2b) instead of (2a):
   a. Math, Advanced: ACM 95ab
   b. ChE, Additional: any two of [ChE 63b, ChE 103c, ChE 105]

3. ChE, Electives: at least 18 additional units of courses from any of: (a) ChE 63b, (b) approved 100 level ChE-listed courses, or (c) ChE 80 (no more than 9 units)

Courses that are used to satisfy the chemical engineering minor requirements cannot be used to satisfy course requirements in the major option(s) not for another minor. All courses to be applied to fulfill the chemical engineering minor requirements must be taken for grades (not P/F), unless the course is only offered P/F. Students must maintain an average grade of B- or higher for all courses with no individual grade lower than a C. Courses taken as part of the chemical engineering minor are counted toward the total 486 units needed for Institute graduation requirements. As a complement to the required courses, SURF research with a relevant chemical engineering faculty member is encouraged.

CHEMISTRY OPTION AND MINOR (CH)

Aims and Scope

The objective of the undergraduate option in chemistry is to produce graduates articulate in the fundamental concepts of the molecular sciences through a combination of coursework and laboratory experiences. The chemistry program at Caltech provides depth in the traditional areas of chemistry—organic and inorganic chemistry, chemical physics, theoretical chemistry, chemical biology, and biochemistry. Breadth in the program is found within the advanced coursework offerings and the specialized interests of the faculty, which may include topics such as: chemical synthesis and catalysis, chemical dynamics and reaction mechanisms, biochemistry, bioinorganic, bioorganic, and biophysical chemistry, nonlinear spectroscopy, electrochemistry, and materials chemistry.

Chemical research at Caltech is highly interdisciplinary, reflecting the increasing importance of molecular understanding to many fields of science. Major initiatives are fostering broad collaborations in molecular medicine, sustainability, environmental science, and nanomaterials.

Caltech offers a Biochemistry Track within the chemistry option. Biochemistry is the study of the chemistry of biological macromolecules and how they enable diverse biological function. This track prepares students in this interdisciplinary area through a combination of coursework offered by Biology, Chemistry, and bioengineering as well as a senior research thesis in a chosen subject area in biochemistry. The Biochemistry Track provides for a wider

range of coursework in Biology. Upon graduation, the diploma will read *Chemistry (Biochemistry).*

The outcome of the undergraduate program in chemistry is to prepare students for advanced graduate study and ultimately careers in teaching and research at colleges and universities, in research for government and industry, in chemical technology from tech startups to corporations, and in leadership and policy positions.

A two-term general chemistry course Ch 1 ab is taken by all first year students. The emphasis is on fundamental principles and their use in systematizing descriptive chemistry. Ch 1 ab must be passed to satisfy the Institute chemistry requirement. The student's qualifications for placing out of Ch 1 ab will only be determined by the performance on a placement examination to be administered in the summer prior to registration. The one-term required laboratory course (Ch 3 a or 3 x) presents basic principles and techniques of synthesis and analysis and develops the laboratory skills and precision that are fundamental to experimental chemistry. Students interested in Chemistry as a major are encouraged – though not required – to take Ch 3 a. Qualified students, with the consent of the instructor and the option representative, are allowed to substitute either Ch 4 a, Ch 8, or Ch/ChE 9 for the core requirement of Ch 3 a or Ch 3 x. First-Year students interested in the Biochemistry track are encouraged to take Bi 8 (as a substitute for the Bi 1 Core requirement) and Bi 9, if possible. First year students intending to major in chemistry are encouraged to take Ch 10 abc, a 3-unit introduction to research activities and opportunities in chemistry for undergraduates.

Beyond the first year, each student in the chemistry option, in consultation with their adviser, selects a suitable course of study under the supervision of the division. The requirements of the option are listed below. A student wishing to deviate from these requirements should submit an alternate curriculum, with justifications, for consideration by their adviser and the Chemistry Curriculum and Undergraduate Studies Committee. The chemistry option representative should be consulted for the future scheduling of courses not offered during the current academic year.

Undergraduates in the option must also take chemistry courses below the 100 level for a letter grade with the exception of the following courses, which are only offered on a pass/fail basis: Ch 1, Ch 3 a or Ch 3 x, Ch 90, and, if taken during the first or second terms as a first-year student, Ch 4 ab, Ch 21 ab, and Ch 41 ab.

Ch Senior Thesis

Chemistry majors are strongly encouraged to undertake a Senior Thesis, though it is not a requirement.

Students attempting a senior thesis in the chemistry option must complete the following requirements.

1. Three terms (27 units) of Ch 82 are to be completed during the junior and/or senior year of study; continued work from research experiences prior to the commencement of the senior thesis is encouraged.

2. By Add-Day of the first term of Ch 82, the candidate will submit a short (five-page) proposal delineating their project for approval by the research mentor and the Chemistry Curriculum and Undergraduate Studies Committee (CUSC).
3. The candidate will present a short progress report (maximum of five pages) at the end of each of the first two terms of Ch 82, describing the status of the research work and any results obtained. Upon evidence of satisfactory effort, the student will be allowed to continue their senior thesis.
4. A thesis of approximately 20 pages (excluding figures and references) will be presented to the mentor and the CUSC at the end of the third term of Ch 82. An oral thesis defense will be arranged by the CUSC. The thesis must be approved by both the research mentor and the CUSC.
5. Upon approval by the research mentor and the CUSC, the Ch 91 requirement for graduation may be satisfied by the written thesis and the progress reports from the first two quarters of Ch 82. A draft of the thesis is to be submitted by Week 7.

Ch Double Majors

For students simultaneously pursuing a degree in a second option, courses taken as *required* courses for that option can also be counted as chemistry electives (requirement 3, below) where appropriate. However, courses that count toward the electives requirement in the other option cannot simultaneously be counted toward satisfying the elective requirement in chemistry.

Graduation Requirements

The courses listed below would constitute a common core for many students in the option.

Any student of the chemistry option whose grade-point average is less than 1.9 will be admitted to the option for the following year only with the special permission of the Division of Chemistry and Chemical Engineering. Passing grades must be earned in the courses that constitute the approved program of study, including those listed below. None of the courses satisfying option requirements may be taken pass/fail.

Ch Option Requirements (non-Biochemistry)

1. Ch 14, Ch 21abc, Ch 41abc, Ch 90, Ma 2, and Ph 2a. Ma 3 is recommended but not required. Students may make the following substitutions: For Ch14 (ESE/Ge 142); for Ch 21a (Ph 2b, Ph 12b, Ch 125a or Ph 125a); for Ch 21c (Ph 2c, Ph 12c, ChE/Ch 164 or Ph 127a). 100-level courses used in substitution for these option requirements may not also be counted towards the five terms of advanced electives. The Ch option requires Ch 90, Oral Presentation. Ch 91 is required to meet the Institute Core Requirement for Scientific Writing. The senior thesis can be used to satisfy the minimum requirement if the third term is taken for grades and a thesis is approved. Ch 91 is not required for students in the Biochemistry Track.

2. A minimum of five terms of laboratory work chosen from Ch 4ab, Ch 5ab, Ch 6, Ch 7, Ch 11, and Ch 15. One non-chemistry laboratory course may be used, chosen from MS 90, Ph 6 and Ph 7, or an alternative with sufficient Chemistry content, by approval of the Option Representative. One term of research, either 10 c (if taken during first or second year) or one term of Ch 82 (Senior Thesis), if taken for grades as the third and final term, may count for one of the five laboratory courses.
3. A minimum of five terms of advanced chemistry electives (which must total at least 45 units) from chemistry course offerings numbered 102 or higher, including cross-listed offerings but excluding Ch 180 and Ch 280. Students may petition to substitute up to but no more than one 100-level elective from another option, if the substituted course has substantial chemistry content. Ch 101 cannot be used to meet the five term requirement but can be used to meet the 45 unit requirement for advanced electives.

The chemistry option strongly encourages students to engage in academic year research, and up to 27 units each of Ch 80 and Ch 82 can count toward the 486-unit requirement.

Ch Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
Ch 41 abc	Organic Chemistry	9	9	9
Ma 2	Sophomore Mathematics	9	-	-
Ph 2 a	Sophomore Physics	9	-	-
Ch 4 ab	Synthesis and Analysis of Organic and Inorganic Compounds	-	9	9
Ch 102	Intro to Inorganic Chemistry	-	-	9
	Electives	18-21	18-27	9-21
	Total	**45-48**	**36-45**	**36-48**
Third Year				
Ch 5 a	Advanced Techniques of Synthesis and Analysis	-	12	-
or Ch 5 b		12	-	-
Ch 15	Chemical Equilibrium and Analysis Laboratory	-	-	10

Ch 21 abc	Physical Chemistry	9	9	9
Ch 14	Chemical Equilibrium and Analysis	-	9	-
Ch 90	Oral Presentation	-	3	-
Ch/ChE 91	Scientific Writing	-	-	3
	Electives	18-30	24-24	32-35
	Total	**45-48**	**45-48**	**45-48**
Fourth Year				
Ch 6	Physical and Biophys. Chemistry Lab	9	-	-
Ch/Bi 110 a	Introduction to Biochemistry	12	-	-
or Ch 7	Advanced Experim. Methods in Bioorganic Chemistry	-	-	9
	Electives	33-36	45-48	27-30
	Total	**45-48**	**45-48**	**45-48**

This typical program is not specifically required for graduation in the option, nor is it in any sense a complete program. Students are expected to work out individual programs suitable for their interests and professional goals in consultation with their advisers. Several representative programs, including sets of possible electives, are shown below. These may well approximate choices by students who intend to do graduate work in conventional areas of chemistry.

Suggested Representative Courses of Study for Those Intending Graduate Work in Particular Areas of Chemistry

	Second Year	*Third Year*	*Fourth Year*
Inorganic Chemistry	Ch 4 ab, Ch 41 abc, Ch 102, Ma 2, Ph 2 a, HSS elective, other elective	Ch 5 b, Ch 14, Ch 21 abc, Ch laboratory, Ch elective(s), Ch 80, Ch 90, Ch/ChE 91, Ch 112, HSS elective	Ch 6 or Ch 15, Ch electives, Ch 82, HSS elective
Chemical Physics	Ch 4 ab, Ch 14, Ch 21 abc, Ch 102, Ma 2, Ma 3, Ph 2 a, HSS elective	Ch 6, Ch 15, Ch 41 abc, Ch elective(s), Ch 80, Ch 90, Ch/ChE 91, HSS elective	Ch 125 ab, Ch laboratory, Ch electives, Ch 82, HSS elective

Organic Chemistry	Ch 4 ab, Ch 41 abc, Ch 102, Ma 2, Ph 2 a, HSS elective, other elective	Ch 5 a, Ch 7, Ch 14, Ch 21 abc, Ch 104, Ch elective(s), Ch laboratory, Ch 80, Ch 90, Ch/ChE 91, HSS elective	Ch 6, Ch 15, Ch electives, Ch 82, HSS elective

Biochemistry Track Requirements

1. Ch 14, Ch 21abc, Ch 41abc, Ch 90, Ma 2, Ph 2a (required for the Ch option), Bi 8 (which can be taken instead of Bi1 to satisfy Core requirements), Bi 9, and Ch/Bi 110ab (Biochemistry) are required. Ma 3 is recommended but not required. Students may make the following substitutions: For Ch14 (ESE/Ge 142); for Ch 21a (Ph 2b, Ph 12b, Ch 125a or Ph 125a); for Ch 21c (Ph 2c, Ph 12c, ChE/Ch 164 or Ph 127a). 100-level courses used in substitution for these option requirements may not also be counted towards the required terms of advanced electives.
2. Four required laboratory courses: Ch 4a, Bi 10, and Ch11 (Biochemistry Lab), and one other laboratory course from Ch4b, Ch6ab, Ch15, Ch7, BMB/Ch 230 (crystallography), or ChE130 (biomolecular engineering lab).
3. In addition to Ch/Bi 110ab, a minimum of four terms of advanced electives (which must total at least 36 units) from biology or chemistry course offerings numbered 102 or higher, including cross-listed offerings but excluding research, chosen in consultation with their academic advisor. Students are strongly encouraged to take electives from the biomolecular and molecular cell biology areas. Ch 101 cannot be used to meet the four-term requirement but can be used to meet the unit requirement for advanced electives.
4. Senior Thesis (three terms) as described above.

The table below shows a year-by-year course recommendation for students in the Biochemistry track.

		Units per term		
		1st	*2nd*	*3rd*
First Year				
Ma 1 abc	Calculus of One and Several Variables	9	9	9
Ph 1 abc	Classical Mechanics and Electromagnetism	9	9	9
Ch 1 ab	General Chemistry	6	9	-

1 HUM/SS	various	9	-	9
Ch 3 a or Ch 3 x	Fundamental Techniques of Experimental Chemistry or Experimental Methods in Solar Energy Conversion	-	6	-
Bi 1 or Bi 1 x_a	The Great Ideas of Biology	-	-	9
Menu course	various	-	-	9
1 elective	various	9	9	-
	Total	**42**	**42**	**45**
Second Year				
Ch 41 abc	Organic Chemistry	9	9	9
Ma 2	Differential Equations	9	-	-
Ph 2 a	Waves	9	-	-
CS1	Introduction to Computer Programming	9	-	-
1 HUM/SS	various	9	9	9
Ch 4 a	Synthesis and Analysis of Organic and Inorganic Compounds	-	9	-
Ch 14	Chemical Equilibrium and Analysis	-	9	-
Bi 8 (if not taken)$_a$	Foundational Principals of Molecular Biology	-	9	-
Bi 9_a	Cell Biology	-	-	9
1 elective	various	-	-	9
Bi 10	Introductory Biology Laboratory	-	-	6
	Total	**45**	**45**	**42**
Third Year				
Ch 21 abc	Physical Chemistry	9	9	9
Ch/Bi 110 ab	Introduction to Biochemistry	12	12	-
Ch 90	Oral Presentation	-	3	-
Ch 11	Biochemistry Laboratory	-	9	-
1 upper-level elective	various	-	-	9

Lab	various	-	-	6
1 HUM/SS	various	9	9	9
1 elective	various	9	-	9
	Total	**39**	**42**	**42**
Fourth Year				
Ch 82	Senior Thesis Research	9	9	9
1 HUM/SS	various	9	9	9
1 upper-level elective	various	9	9	9
1 elective	various	9	9	9
	Total	**36**	**36**	**36**

[a] Bi 8 and Bi 9 can be taken First-year instead of Bi 1.

Ch Minor Requirements
The chemistry minor is intended to supplement one of Caltech's undergraduate degrees. It is designed for students who wish to broaden their studies beyond their major to include chemistry. Students completing the chemistry minor requirements will have the phrase "minor in chemistry" added to their transcripts.

1. 18 units of organic chemistry, taken from Ch 41 abc.
2. 18 units of physical chemistry, taken from Ch 21 abc (or substitute as specified for the major).
3. 27 units of advanced chemistry electives numbered Ch 102 or above, approved by their designated chemistry adviser or the option representative.
4. 9 or more units of a chemistry laboratory course from Ch 4ab, Ch 5 ab, Ch 6 ab, Ch 7, Ch 11 or Ch 15. No substitutions are allowed.

All courses to be applied to fulfill the minor requirements must be taken for grades. Courses taken as part of the chemistry minor are counted toward the total 486 units needed for Institute graduation requirements. To enroll in the program, the student should meet and discuss their plans with the option representative. In general, approval is contingent on good academic performance by the student and demonstrated ability for handling the heavier course load. Courses that are used to satisfy the Chemistry minor requirements cannot be used to satisfy course requirements in another major.

COMPUTATION AND NEURAL SYSTEMS OPTION (CNS)

Aims and Scope

The undergraduate CNS option provides a foundation in math, physics, biology and computer science to prepare students for interdisciplinary graduate studies in neuroscience and career paths that involve computational applications inspired by properties of biological systems, such as artificial intelligence and computer vision. By graduation, students will have acquired knowledge in neurobiology, computation principles across different systems, methods used in modern neuroscience research, as well as the ability to critically evaluate and understand neuroscience literature, and be able to work in a team and communicate effectively.

To accomplish these goals, students are expected to complete a series of math and physics courses to establish solid quantitative skills. Then, they are expected to take two groups of courses, of which one has a biology focus, while the other has a CS focus. Through these courses, students are exposed to different sub-disciplines of neuroscience while also acquiring the quantitative skills needed in graduate research and industry jobs. Students will receive instruction in scientific communications through SEC 10 and SEC 11, SEC 12, SEC 13, or Bi/BE 24.

Undergraduate research is encouraged both during the academic year and through participation in summer research programs.

Students with a grade-point average lower than 1.9 will not be allowed to continue in the option except with special permission from the option representative.

CNS Option Requirements

1. Take 4 courses from the extended math core:
   a. *Differential Equations (Ma 2 or equivalent listed below):*
   i. Intro Applied Mathematics for the Physical Sciences (ACM 95 ab)
   ii. Numerical Methods for Integrals, PDEs, Spectral Theory (ACM 101 ab)
   iii. Theory and Implementation of Linear Algebra, Approximation Theory, and Differential Equations (ACM 106 ab)
   iv. Analysis (Ma 108 abc) or Topology (Ma 109 abc)
   b. *Probability and Statistics (Ma 3 or equivalent listed below):*
   i. Statistical Inference in the Biological Sciences (BE/Bi 103 b)
   ii. Bayesian Statistics (Ec/ACM/CS 112)
   iii. Introduction to Probability Models (ACM 116)
   iv. Probability Theory and Computational Mathematics (CMS/ACM 117)
   v. Bayesian Statistics and Data Analysis (Ge/Ay 117)
   vi. Statistical Inference (IDS/ACM/CS 157)
   c. *Other math core:*
   i. Algebra (Ma 5 abc), Discrete Math (Ma 6 abc)
   ii. Applied Linear Algebra (ACM 104)
   iii. Linear Analysis with Applications (ACM 107 ab)
   iv. Mathematics in Biology (Bi/CNS/NB 195)

d. *Analytical science (choose two courses from one of the following sets):*
i. Sophomore Physics: Ph 2 abc, Ph 12 abc.
ii. Advanced Physics: Ph 106 abc, Ph 125 abc.
iii. Optics: Aph 23, Aph 24, Ph 107.
iv. Organic Chemistry: Ch 41 abc.
v. Physical Chemistry: Ch 21 abc.
vi. Chemical Engineering: ChE 63 ab, ChE 62.
vii. Electrical engineering: EE 44, EE 119 ab, EE 114 ab
viii. Mechanical Engineering: ME 11 abc, ME 12 abc

2. Demonstration of competency in computer programming or computer science by taking CS 1, CS 2, and CS 3; or more advanced alternatives listed below:
   i. Systems (CS 24)
   ii. Decidability and Tractability (CS 21)
   iii. Algorithms (CS 38)
   iv. Data Analysis in Biology (BE 103 ab)
   v. Introduction to Computational Biology and Bioinformatics (Bi/BE/CS 183)
   vi. Another course approved by the option representative.
3. Bi/CNS 162 and 9 units of laboratory courses taken from the following list: CS/CNS 171, CS/CNS 174, EE 45, EE 90, EE 91 ab, ME 72 ab, ME 50ab, BE/EE/MedE 189 a, BE/CS 196a, Bi/BE 227, Bi/CNS/BE/NB 230, ME/CS/EE 134, or an equivalent course.
4. SEC 10 and SEC 11, SEC 12, or SEC 13; or Bi/BE 24.
5. Bi 8, Bi 9, NB/Bi/CNS 150, Bi/CNS/NB 164.
6. Choose five CNS-(co)labeled 3-digit courses.
7. 45 units of electives chosen from either advanced EAS courses or advanced science courses offered by BBE, CCE, GPS, or PMA divisions.

No course can count for more than one of the CNS requirements above, and all courses used to satisfy the option requirements must be taken on grades.

Senior Thesis (optional)
Either one of the two paths can be taken for graduation.

a. 45 units of electives; or
b. 27 units of electives, and three terms (27 units) taken of a senior thesis, completed in either junior or senior year in CNS *X abc* Senior thesis.

CNS Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
First Year				

CS 1	Introduction to Computer Programming	9	-	-
CS 2	Introduction to Programming Methods	-	9	-
	First-Year Humanities	9	9	9
	First-Year Core	27	27	27
	Total	**45**	**45**	**36**
Second Year				
Ph 2 ac	Waves, Statistical Mechanics	9	-	9
Ma 2	Sophomore Mathematics	9	-	-
Ma 3	Sophomore Mathematics	-	9	-
ACM 95 ab	Intro. Methods of Applied Math	-	12	12
EE 111	Signals and systems	9	-	-
Bi 8, 9	Molecular, Cell Biology	-	9	9
NB 150	Introduction to Neuroscience	-	-	10
	HSS Electives	9	9	9
	Electives	9	9	-
	Total	**45**	**48**	**49**
Third Year				
BE 103a	Introduction to Data Analysis in Biological Sciences	9	-	-
BE 103b	Statistical Inference in the Biological Sciences	-	9	-
Bi 164	Tools in Neurobiology	9	-	-
CS 156 a	Learning Systems	9	-	-
Bi 162	Cellular and Systems Neuroscience Lab	-	12	-
BE/CS 191 a	Comparative Nervous Systems	-	9	-
	Engineering Lab	-	-	9
	HSS Electives	9	9	9
	Electives	9	9	27
	Total	**45**	**48**	**45**

Fourth Year				
CNS 187	Neural Computation	9	-	-
CNS 186	Vision: From Computational Theory to Neuronal Mechanisms	-	12	-
CS 159	Advanced Topic in Machine Learning	-	-	9
SEC 10, SEC 11-13	Scientific Communication	3	-	3
	HSS Electives	9	9	9
	Electives	18	18	18
	Total	**39**	**39**	**39**

COMPUTER SCIENCE OPTION AND MINOR (CS)

Aims and Scope

Study in the computer science option within the Computing & Mathematical Sciences department emphasizes rigor and creativity, and is good preparation either for graduate study followed by a research career, or for a variety of professional or entrepreneurial occupations.

The option introduces students to the mathematical and engineering foundations of the discipline. It provides considerable flexibility in course selection, together with a capstone project giving an opportunity for independent work in an area of the student's choice. Individual programs will be worked out in consultation with faculty advisers (the materials at cms.caltech.edu/academics/ugrad_cs may be helpful for this purpose).

Any student in the computer science option whose grade-point average is less than 1.9 at the end of the academic year in the subjects listed in the option requirements may be refused permission to continue work in the option.

CS Double Majors

Students interested in simultaneously pursuing a degree in a second option must fulfill all the requirements of the computer science option. Specific courses that are explicitly required by both options only need to be taken once. For example, if both options require CS 38, then it can count for both. However, elective courses that satisfy the "Advanced CS" requirement or the "Breadth" requirement cannot be double counted. That is, Requirements 4 and 8 must be fulfilled using courses that are not simultaneously used for fulfilling a requirement of the second option. To enroll in the program, the student should meet and discuss their plans with the option representative. In general,

approval is contingent on good academic performance by the student and demonstrated ability for handling the heavier course load.

CS Option Requirements

1. CS fundamentals. CS 1 or CS 1X; CS 2; CS 3x; CS 18; CS 4.
2. Intermediate CS. CS 21; CS 24; CS 38.
3. CS Project Sequence. One of the following:
    a. An undergraduate thesis (CS 80abc) supervised by a CS faculty member.
    b. A project in computer science, mentored by the student's academic adviser or a sponsoring faculty member. The sequence must extend at least two quarters and total at least 18 units of CS 81abc or CS 82.
    c. Any of the following three-quarter sequences. Each of the sequences is expected to be available (nearly) yearly.
        i. Graphics: CS/CNS 171 and two other CS 17x courses. The three courses can include a 9 or 12 unit CS81abc focused on graphics, if approved by a CS faculty member for this purpose.
        ii. Learning & Vision: At least three courses chosen from EE/CNS/CS 148, CMS/CS/CNS/EE/IDS 155, CS/CNS/EE 156 ab, IDS/ACM/CS 157, ACM/CS/EE/IDS 158, CS/CNS/EE/IDS 159, CNS/Bi/EE/CS/NB 186, CNS/Bi/Ph/CS/NB 187, Ec/ACM/CS 112, including at least one of 148, 156 b, 159, or 186.
        iii. Networks & Communication: Three courses selected from CS 141, CS/EE/IDS 143, CMS/CS/EE/IDS 144, CS/EE 145, CS/EE 146, EE/Ma/CS 126a, EE/Ma/CS 126b, EE 127, EE/CS/EST 135, EE 160, EE 161.
        iv. Quantum & Molecular Computing: At least three courses chosen from BE/CS/CNS/Bi 191 ab, BE/CS 196 ab, ChE 130, Ph/CS 219 abc.
        v. Robotics: At least three courses chosen from ME/CS/EE 133 ab, ME/CS/EE 134, ME/CS/EE 169, ME/CDS/EE 234 ab, ME/CDS/EE 235 ab.
        vi. Programming Languages: At least three of the courses CS 115, CS 128, CS 131, and CS 164.
4. Advanced CS. A total of 72 CS units that are not applied to requirements 1 or 2 above, and that either (i) are numbered CS 114 and above or (ii) are in satisfaction of requirement 3 above. Included in these units must be at least one of CS 124, CS 137, CMS/CS/IDS 139, CS/IDS 142, CS/EE/IDS 143, CMS/CS/EE/IDS 144, CS/IDS 150 a, or CS 151.
5. Mathematical fundamentals. Ma 2/102; Ma 3/103; (CS 13 or Ma/CS 6a or Ma 121a).
6. Communication fundamentals. SEC 10, and one of SEC 11-13.
7. Scientific core electives. 18 units selected from the following courses: BE/Bi 25, Bi 8, Bi 9, Ch 21 abc, Ch 41 abc, Ph 2 abc, or Ph 12 abc. Advanced 100+ courses in Ay, Bi, BE, Ch, CNS, Ge, MedE, or Ph with a strong scientific component can be used to

satisfy this requirement with approval from the option representative.

8. Breadth. In addition to all of the above requirements, 30 units in Ma, ACM, or CS; 18 units in EAS or Ma; and 9 units not labeled PE, PVA or SA.

Units used to fulfill the Institute Core requirements do not count toward any of the option requirements. Pass/fail grading cannot be elected for courses taken to satisfy option requirements. Passing grades must be earned in a total of 486 units, including all courses used to satisfy the above requirements.

CS Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
	Scientific Fundamentals	9	9	-
Ma 2, Ma 3	Sophomore Mathematics	9	9	-
CS 1	Intro. to Computer Programming[1]	9	-	-
CS 2	Intro. to Programming Methods[1]	-	9	-
CS 4	Fundamentals of Computer Program	-	9	-
CS 13	Math Foundations for Computing	-	-	9
CS 21	Decidability and Tractability	-	9	-
CS 3x	Introduction to Software Design in C	-	-	6
CS 38	Introduction to Algorithms	-	-	9
	HSS electives	9	-	18
	Other electives	-	-	9
	Total	**45**	**45**	**45**
Third Year				
	CS courses	-	9	9
CS 24	Intro. to Computing Systems	9	-	-
	CS project	9	9	9
	HSS electives	9	9	9

SEC 10	Technical Seminar Presentations	-	-	3
	EAS/Ma courses	9	9	9
	Other electives	9	9	-
	Total	**45**	**45**	**39**
Fourth Year				
	CS courses	9	9	-
	HSS electives	9	9	9
	EAS/Ma courses	9	9	9
	Other electives	18	9	18
	Total	**45**	**36**	**36**

[1] Commonly taken during the first year.

CS Minor

The computer science minor is intended to supplement one of Caltech's undergraduate degrees and is designed for students who wish to broaden their knowledge beyond their normal major or who may wish to pursue a graduate program involving computer science. Students completing the computer science minor requirements will have the phrase "minor in computer science" added to their transcripts.

CS Minor Requirements

1. CS fundamentals. CS 1 or CS 1X; CS 2; CS 3x; CS18.
2. Mathematical fundamentals. Ma 2; Ma 3; (CS 13 or Ma/CS 6a or Ma 121a).
3. Intermediate CS. CS 21; CS 24; CS 38.
4. Advanced CS. 9 CS units numbered 114 or above that are not applied to the above requirements and are not simultaneously used for fulfilling a requirement of the student's major option. Pass/fail grading cannot be elected for courses taken to satisfy option requirements. Courses taken as part of the computer science minor are counted toward the total 486 units needed for Institute graduation requirements. To enroll in the program, the student should meet and discuss their plans with the option representative. In general, approval is contingent on good academic performance by the student and demonstrated ability for handling the heavier course load.

CONTROL AND DYNAMICAL SYSTEMS MINOR (CDS)

Aims and Scope
Control and dynamical systems (CDS) may be pursued as a minor concentration by undergraduates who are taking degrees in science, mathematics, or engineering. The CDS minor is intended to supplement one of Caltech's normal undergraduate degrees and is designed for students who wish to broaden their knowledge beyond their normal major or who may wish to pursue a graduate program involving control or dynamical systems. Students completing the minor requirements below in CDS will have the phrase "minor in control and dynamical systems" added to their transcripts and their graduating degree materials.

CDS Minor Requirements
- Complete CDS 110 or CDS 131 and CDS 232
- Complete nine additional units in CDS courses, chosen from CDS 110, CDS 131, CDS 212, CDS 232, CDS 233, CDS 242, CDS 243, CDS 244, CDS 245.
- Complete a three-term senior thesis approved by the CDS faculty.

All CDS courses to be applied to fulfill the CDS minor requirements must be taken for grades, and students must obtain a grade of B or higher. The senior thesis requirement may be satisfied by completing a three-term senior thesis in the student's major option but on CDS subject matter, with the approval of the thesis topic by the CDS option representative, or by taking CDS 90 abc.

Courses that are used to satisfy the CDS minor cannot be used to satisfy course requirements in the major options, with the exception that CDS 110 may be used in EAS options where this is part of their requirements (e.g., ChE, EE, ME) and the senior thesis requirement may be used to satisfy requirements for major options that require a senior thesis. Courses taken as part of the CDS minor are counted toward the total 486 units needed for Institute graduation requirements.

A typical course sequence would be to take either CDS 110 or CDS 232 in the junior year, followed by the remaining courses and the senior thesis in the senior year. Alternatively, it is possible to take all requirements in the senior year. In addition to the requirements above, CS 1 and CS 2 are highly recommended.

ECONOMICS OPTION (EC)

Aims and Scope
The economics option provides students with an understanding of the basic principles underlying the functioning of economic institutions. It offers a modern quantitative approach seldom available at the undergraduate level. The emphasis on economic principles and modern methodology provides students with an excellent preparation for graduate study in economics, as well as for professional work in

the fields of business, law, economics, and government.

The option is highly flexible, allowing students to combine their study of economics with other fields, particularly mathematics and computer science. The core of the option consists of an economic theory component, a data analysis component, an applied microeconomic component, and a macroeconomic/growth component, and a basic math component (statistics/probability theory and linear algebra/analysis component). Students are strongly encouraged to supplement this core with additional electives in economics, political science, and mathematics.

Expected learning outcomes from completing the economics option include:

- a proficiency in applying economic models to understand economic institutions;
- a proficiency in analyzing field and experimental data to prove causal relationships between economic variables, to test economic theories, and to predict economic outcomes;
- an understanding of the causes of regional and global long-term economic growth as well as the causes and consequences of economic crises throughout history;
- an understanding of the role of market prices in allocating resources and affecting the distribution of wealth;
- an appreciation of strategic behavior and asymmetric information in economic and social interactions; and
- an appreciation of the role of technological change and politics in shaping economic policies.

Note: The official source on requirements for graduation is the Caltech catalog from the year in which a student began studies at Caltech. Please see the catalog online, from this and previous years, for information regarding the applicable option requirements.

Ec Option Requirements

1. Ec 11.
2. Theory: Ec 121 ab and PS/Ec 172.
3. Data analysis: Ec 122.
4. Applied microeconomics: one of Ec/Psy 108, Ec/Psy 109, Ec 105, Ec 135 or Ec 136.
5. Macroeconomics and growth: one of Ec 129, 130, or Ec 140.
6. Statistics/Probability Theory: Ma 3.
7. Linear Algebra/Analysis: ACM 104 (Linear Algebra) or Ma 108a (Analysis). (Students intending to pursue graduate studies in economics are strongly encouraged to complete both Linear Algebra and Analysis.)
8. 45 additional units of advanced economics and social science courses. (Courses that are used to fulfill the Institute advanced social science requirement [courses numbered 100 and above] will also count toward this requirement.) Students may also take classes from the following list in partial fulfillment of this requirement: any BEM course except BEM 102; ACM 113 and

ACM/EE/IDS 116.

9. 27 additional units of advanced science, social science, mathematics, and engineering courses. The requirement cannot be satisfied by any course with a number less than 100.
10. Passing grades must be earned in a total of 486 units, including all courses used to satisfy the above requirements.
11. Writing/oral presentation courses: a scientific writing requirement course, and a three-unit course in oral communication, offered by any division (some options combine these two requirements into one course, that can be taken to satisfy this requirement), or En/Wr 84. The course used to satisfy this requirement must be taken on grades.

Ec Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
ACM 104 or Ma 108a	Linear Algebra or Analysis respectively	9		
Ma 3	Sophomore Mathematics	-	9	-
Menu Course		-	-	9
Ec 11	Introduction to Economics	9	-	-
PS 12	Introduction to Political Science	-	-	9
Electives [1]		27	27	27
	Total	**45**	**36**	**45**
Third Year				
Ec 105	Firms, Competition, and Industrial Organization	9	-	-
Ec 121ab	Theory of Value	9	9	-
PS/Ec 172	Game Theory	-	9	-
Ec 122	Econometrics	9	-	-
Electives [1]		18	27	45
	Total	**45**	**45**	**45**
Fourth Year				
En/Wr 84 (or 3 unit course in oral communication and a scientific writing requirement course)		-	-	9
Electives [1]		45	45	36

	Total	**45**	**45**	**45**

[1] *See option requirements 5 and 7.*

ELECTRICAL ENGINEERING OPTION (EE)

Aims and Scope

The objective of the undergraduate program in Electrical Engineering at Caltech is to produce graduates who will attain careers and higher education that ultimately lead to leadership roles in academia, industry, and government in areas of rapidly advancing interdisciplinary technology related to telecommunications, solid-state, robotics, information, computer and electrical systems.

The program prepares its students for either graduate study, entrepreneurial careers, or research and development work in government or industrial laboratories. It inspires them to undertake careers and professional practices that provide an opportunity to address the pressing technological needs of society. It accomplishes this by building on the core curriculum to provide a broad and rigorous exposure to the fundamentals (e.g., math, science, and principles of engineering) of electrical engineering. EE's other program objectives are multiple. The program strives to maintain a balance between classroom lectures and laboratory and design experience, and it emphasizes the problem formulation, system-design, and problem solving skills that are essential to any engineering discipline. The program is also intended to develop in each student self-reliance, creativity, teamwork ability, professional ethics, communication skills, and an appreciation of the importance of contemporary issues and lifelong intellectual growth. For interested students, there are opportunities to conduct research with a faculty member.

Students electing this option normally choose to take the introductory seminar EE 2 as a first-year elective. The formal study of electrical engineering begins in the sophomore year with courses such as, deterministic analysis of systems and circuits, EE 44; mathematics of electrical engineering, EE 55; introduction to digital logic and embedded systems, EE/CS 10 ab; physics of electrical engineering, EE/APh 40; and electronic systems and laboratory, EE 45. The junior year features the fundamentals of signal-processing systems and transforms, EE 111; introduction to probability models, ACM/EE/IDS 116; electromagnetic engineering, EE 151, or fundamentals of information transmission and storage, EE/CS/IDS 160; and analog electronics projects laboratory, EE 90. In the senior year, the student will be asked to demonstrate their ability to formulate and carry out a design or research project by taking the senior project design laboratory, EE 91 ab, or senior thesis, EE 80 abc. In addition, the student throughout their studies and especially in the senior year, will have a significant opportunity to take elective courses that will allow them to explore earlier topics in depth, or to investigate topics that have not been covered previously.

A motivated student may choose to pursue a specialization within Electrical Engineering by choosing one of the tracks offered within the Electrical Engineering option. These tracks allow the student to focus on a specific area within EE while still attaining a broad background in Electrical Engineering. Upon graduation the diploma will read Electrical Engineering (track name). The available tracks are Circuits & Electronics, Computer Engineering, Intelligent Systems, Medical Engineering and Photonics and Quantum.

A student whose interests lie in the electrical sciences but who wishes to pursue a broader course of studies than that allowed by the requirements of the Electrical Engineering option may elect the Engineering and Applied Science option.

Attention is called to the fact that any student who has a grade-point average less than 1.9 at the end of the academic year in the subjects listed under electrical engineering may be refused permission to continue work in this option.

EE Double Majors

The Electrical Engineering option allows interested students to declare Electrical Engineering as one of the majors in a double major pursuit. To enroll in the program, the student should meet and discuss their plans with the Undergraduate Option Representative. In general, approval is contingent on good academic performance by the student and demonstrated ability for handling the heavier course load. For students simultaneously pursuing a degree in a second option, courses taken as required courses for that option can also be counted as EE electives where appropriate. However, courses that count toward the electives requirement in the other option cannot be simultaneously counted toward satisfying the electives requirement in EE. To qualify for an Electrical Engineering degree, the student would need to complete all option requirements.

EE Option Requirements

1. Ma 2, EE 2, SEC10, one of SEC 11-13, EE/CS 10ab, EE/APh 40, EE 44, 45, 55, 90, and 111.
2. Two of Ph 2a, Ph 2b, Ph2c, or APh/EE 23 (Ph 12 can replace Ph 2).
3. Three of ACM 95a, ACM 95b, ACM/IDS 104, or ACM/EE/IDS 116.
4. EE 151 or EE/CS/IDS 160.
5. EE 91ab or this requirement can be waived if a student completes EE 80abc.
6. In addition to the above courses, 72 units selected from any EE course numbered over 100 or any other EE-related engineering or science course numbered over 100 (such as CDS 110 or CNS/Bi/Ph/CS/NB 187) with approval of the Undergraduate Option Representative.
7. Passing grades must be earned in a total of 486 units, including courses listed above. Courses used to satisfy requirements 1 through 6 must be taken for grades, unless they are only offered pass/fail.

EE Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
EE 44	Deterministic Analysis of Systems and Circuits	12	-	-
EE 55	Mathematics of Electrical Engineering	12	-	-
EE/APh 40	Physics of Electrical Engineering	-	9	-
EE 45	Electronics Systems and Laboratory	-	-	12
EE/CS 10 ab	Introduction to Digital Logic and Embedded Systems	-	6	6
Ma 2	Differential Equations	9	-	-
Ph 2 ab	Sophomore Physics	9	9	-
	Electives	-	9	9
	HSS Electives[1]	-	9	18
	Total	**42**	**42**	**45**
Third Year				
EE 111	Signal-Processing Systems and Transforms	9	-	-
EE 151	Electromagnetic Engineering	-	-	9
EE/CS/IDS 160	Fundamentals of Information Transmission and Storage	-	9	-
EE 90	Analog Electronics Project Lab	-	-	9
ACM/EE/IDS 116	Introduction to Probability Models	9	-	-
ACM 95 ab	Intro. Methods of Applied Math.	-	12	12
SEC 10	Technical Seminar Presentations	3	-	-
one of SEC 11-13	Written Communication	-	3	-
	EE Electives[2]	9	9	-

	Electives	9	-	9
	HSS Electives [1]	9	9	9
	Total	**48**	**42**	**48**
Fourth Year (for project)				
EE 91 ab	Experimental Projects in Electronic Circuits	9	6	-
	EE Electives[2]	18	18	9
	Electives	-	9	18
	HSS Electives[1]	9	9	9
	Total	**36**	**42**	**36**
Fourth Year (for thesis)				
EE 80 abc	Senior Thesis	9	9	9
	EE Electives[2]	18	18	9
	Electives	-	-	9
	HSS Electives[1]	9	9	9
	Total	**36**	**36**	**36**

[1] See Institute requirements for specific rules regarding humanities and social sciences.
[2] See EE Option requirement 6 for specific rules regarding EE electives.

This typical program is not specifically required for graduation in the option. Students are expected to work out individual programs suitable to their interests and professional goals in consultation with their advisors.

EE Circuits & Electronics Track Requirements

Advanced electronic systems is a ubiquitous and fast-growing area that continues to have a significant impact on society. The Circuits and Electronics track provides an opportunity for EE students to develop depth of knowledge in analog, mixed-signal and digital circuits and electronics for a wide range of applications; from sensing and communication to space and quantum engineering. Many of the courses in this track have lab and project components, which will prepare students for future jobs in industry and research in graduate school.

1. Ma 2, EE 2, SEC 10, one of SEC 11-13, EE/APh 40, EE 44, 45, 55, and 111.
2. Four classes chosen from EE 113, EE 114a, EE 114b, EE124, EE/CS 119a, EE/CS 119b, EE 153.
3. One class chosen from EE 151, 152, 154, 158.

4. EE 80abc or EE 91ab.
5. In addition to the above courses, 99 units selected from any EE course excluding EE 99, or Ph 2abc (Ph12 may be substituted for Ph2), or ACM 95ab; 45 of which must be numbered over 100.
6. Passing grades must be earned in a total of 486 units, including courses listed above. Courses used to satisfy requirements 1 through 5 must be taken for grades, unless they are only offered pass/fail.

EE Circuits & Electronics Track Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
EE 44	Deterministic Analysis of Systems and Circuits	12	-	-
EE 55	Mathematics of Electrical Engineering	12	-	-
EE/APh 40	Physics of Electrical Engineering	-	9	-
EE 45	Electronics Systems and Laboratory	-	-	12
EE/CS 10 ab	Introduction to Digital Logic and Embedded Systems	-	6	6
Ma 2	Differential Equations	9	-	-
Ph 2 ab	Sophomore Physics	9	9	-
	Electives	-	9	9
	HSS Electives [1]	-	9	18
	Total	**42**	**42**	**45**
Third Year				
EE 111	Signal-Processing Systems and Transforms	9	-	-
EE/MedE 124	Mixed-mode Integrated Circuits	9	-	-
EE 113	Feedback and Control Circuits	-	9	-
EE/MedE 114 ab	Analog Circuit Design	-	12	12
ACM 95 a	Intro. Methods of Applied Math.	-	12	-

EE 151	Electromagnetic Engineering	-	-	9
EE 90	Analog Electronics Project Lab	-	-	9
SEC 10	Technical Seminar Presentations	3	-	-
one of SEC 11-13	Written Communication	-	3	-
	EE Electives[2]	9	-	-
	Electives	-	-	9
	HSS Electives [1]	9	9	9
	Total	**39**	**45**	**48**
Fourth year (for project)				
EE 91 ab	Experimental Projects in Electronic Circuits	9	6	-
	EE Electives[2]	18	12	9
	Electives	-	9	18
	HSS Electives [1]	9	9	9
	Total	**36**	**36**	**36**
Fourth year (for project)				
EE 80 abc	Senior Thesis	9	9	9
	EE Electives[2]	18	12	9
	Electives	-	9	9
	HSS Electives [1]	9	9	9
	Total	**36**	**39**	**36**

[1] See Institute requirements for specific rules regarding humanities and social sciences.
[2] See EE Circuits and Electronics Track requirement 5 for specific rules regarding EE electives.

This typical program is not specifically required for graduation in the option. Students are expected to work out individual programs suitable to their interests and professional goals in consultation with their advisors.

EE Computer Engineering Track Requirements

Computer Engineering lies at the intersection of computer science and electrical engineering and exploits the advances in semiconductor technology and algorithms to create ever more complex digital systems to satisfy the computing needs of society. The Computer Engineering track allows EE students to advance their knowledge in digital and computer systems while still maintaining a broad background in Electrical Engineering.

1. Ma 2, EE 2, SEC 10, one of SEC 11-13, EE/CS 10ab, EE/Aph 40, EE 44, 45, 55, 111, and 188.
2. EE 110abc or EE/CS 119abc; EE 91ab may be substituted for EE 110c or EE/CS 119c.
3. CS 3, CS 24, and CS 124.
4. In addition to the above courses, 96 units selected from any EE course excluding EE 99, or Ph 2abc (Ph 12 may be substituted for Ph 2), or ACM 95ab; 45 of these units must be numbered over 100.
5. Passing grades must be earned in a total of 486 units, including courses listed above. Courses used to satisfy requirements 1 through 4 must be taken for grades, unless they are only offered pass/fail.

EE Computer Engineering Track Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
EE 44	Deterministic Analysis of Systems and Circuits	12	-	-
EE 55	Mathematics of Electrical Engineering	12	-	-
EE/APh 40	Physics of Electrical Engineering	-	9	-
EE 45	Electronics Systems and Laboratory	-	-	12
EE/CS 10 ab	Introduction to Digital Logic and Embedded Systems	-	6	6
CS 3	Introduction to Software Design	-	-	9
Ma 2	Differential Equations	9	-	-
Ph 2 ab	Sophomore Physics	9	9	-
	Electives	-	9	9

	HSS Electives [1]	-	9	9
	Total	**42**	**42**	**45**
Third Year				
EE/CS 119 abc -or- EE 110 abc	Advanced Digital Systems Design Embedded Systems Design Laboratory	9	9	9
EE 188	Computer Architecture	-	-	9
EE 111	Signal-Processing Systems and Transforms	9	-	-
EE 151	Electromagnetic Engineering	-	-	9
EE/CS/IDS 160	Fundamentals of Information Transmission and Storage	-	9	-
EE 90	Analog Electronics Project Lab	-	-	9
ACM/EE/IDS 116	Introduction to Probability Models	9	-	-
ACM 95 a	Intro. Methods of Applied Math.	-	12	-
SEC 10	Technical Seminar Presentations	3	-	-
one of SEC 11-13	Written Communication	-	3	-
	HSS Electives [1]	18	9	9
	Total	**48**	**42**	**45**
Fourth Year				
CS 24	Introduction to Computing Systems	9	-	-
CS 124	Operating Systems	-	-	12
	EE Electives[2]	9	12	9
	Electives	9	18	9
	HSS Electives [1]	9	9	9
	Total	**36**	**39**	**39**

[1] See Institute requirements for specific rules regarding humanities and social sciences.
[2] See EE Computer Engineering Track requirement 4 for specific rules regarding EE electives.

This typical program is not specifically required for graduation in the option. Students are expected to work out individual programs suitable to their interests and professional goals in consultation with their advisors.

EE Intelligent Systems Track Requirements

Intelligent systems collect and analyze data to find patterns, make predictions and perform complex mechanical tasks. Their design involves specialized hardware and software components used to process large amounts of data in real time and thus requires a strong foundation in sensing and signal processing technologies, algorithms, statistics, learning, and control.

1. Ma 2, EE 2, SEC 10, one of SEC 11-13, EE/APh 40, EE 44, and 55.
2. Math: ACM/IDS 104, ACM/EE/IDS 116 or CMS/ACM 117, IDS/ACM/CS 157, and ACM 95a.
3. Signals, Learning, Control and Communication: EE 111, CS/CNS/EE 156a, CDS 110, and EE/CS/IDS 160.
4. Depth: EE 80abc or, with approval of the Undergraduate Option Representative, a sequence of 3 courses (27 units) formed from systems-related EE, ACM, CS, or CDS courses over 100. Example sequences include: Information and Coding: EE/Ma/CS 126ab, EE/Ma/CS/IDS 127; Signal Processing: EE 112, EE 164, ACM/EE/IDS 170; Learning: IDS/ACM/CS 158, CMS/CS/CNS/EE/IDS 155, CS/CNS/EE 156b or CS/CNS/EE/IDS 159; Control: CDS 131, CDS 112, ME/CS/EE 129.
5. In addition to the above courses, a total of 99 units selected from any EE course excluding EE 99, or Ph 2abc (Ph 12 may be substituted for Ph 2), Ph 3, ACM 95b, or, with approval of the Undergraduate Option Representative, any systems-related ACM, CS, or CDS course numbered over 100; these courses must include at least one course selected from EE 45, ME/CS/EE 129, CS/EE/IDS 166, CNS/Bi/EE/CS/NB 186, or Ph 3; 45 of these units must be numbered over 100. Any course listed in item 5 that has not been taken for depth can also be taken to fulfill requirement 6.
6. Passing grades must be earned in a total of 486 units, including courses listed above. Courses used to satisfy requirements 1 through 5 must be taken for grades, unless they are only offered pass/fail.

EE Intelligent Systems Track Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				

EE 44	Deterministic Analysis of Systems and Circuits	12	-	-
EE 55	Mathematics of Electrical Engineering	12	-	-
EE/APh 40	Physics of Electrical Engineering	-	9	-
EE 45	Electronics Systems and Laboratory	-	-	12
EE/CS 10ab	Introduction to Digital Logic and Embedded Systems	-	6	6
Ma 2	Differential Equations	9	-	-
Ph 2 ab	Sophomore Physics	9	9	-
	EE Electives[2]	-	-	9
	Electives	-	-	9
	HSS Electives [1]	-	18	9
	Total	**42**	**42**	**45**
Third Year				
ACM 95 a	Intro. Methods of Applied Math.	-	12	-
ACM/EE/IDS 116	Introduction to Probability Models	9	-	-
ACM/IDS 104	Applied Linear Algebra	9	-	-
IDS/ACM/CS 157	Statistical Inference	-	-	9
CDS 110	Introduction to Feedback Control Systems	-	-	9
EE 111	Signal-Processing Systems and Transforms	9	-	-
CS/CNS/EE 156a	Learning Systems	9	-	-
EE/CS/IDS 160	Fundamentals of Information Transmission and Storage	-	9	-
SEC 10	Technical Seminar Presentations	3	-	-
one of SEC 11-13	Written Communication	-	3	-
	EE Electives[2]	-	9	9
	Electives	-	-	9

	HSS Electives [1]	9	9	9
	Total	**48**	**42**	**45**
Fourth Year				
EE 80 abc	Senior Thesis	9	9	9
	EE Electives[2]	18	9	9
	Electives	-	9	9
	HSS Electives [1]	9	9	9
	Total	**36**	**36**	**36**

[1] See Institute requirements for specific rules regarding humanities and social sciences.
[2] See EE Intelligent Systems Track requirement 5 for specific rules regarding EE electives.

This typical program is not specifically required for graduation in the option. Students are expected to work out individual programs suitable to their interests and professional goals in consultation with their advisors.

EE Medical Engineering Track Requirements

The development of devices and engineering systems for medicine continues to be an exciting and growing focus in electrical engineering. The Medical Engineering track allows EE students to gain knowledge in the domains of bioelectronics, biophotonics, medical devices, and medical imaging, in addition to the fundamentals of EE.

1. Ma 2, EE 2, SEC 10, one of SEC 11-13, EE/APh 40, EE 44, 55, and 111.
2. EE 45 or a sequence consisting of APh/EE 23 and APh/EE 24.
3. 45 units of EE courses cross-listed with MedE and numbered over 100.
4. EE 80abc or EE/MedE/BE 189ab.
5. In addition to the above courses, 96 units selected from any EE course excluding EE 99, or Ph 2abc (Ph 12 may be substituted for Ph 2), ACM 95ab, or with approval of the Undergraduate Option Representative, any EE-related MedE, BBE or CCE course numbered over 100 (such as CNS/Bi/Ph/CS/NB 187 or MedE 101); 45 of these units must be numbered over 100.
6. Passing grades must be earned in a total of 486 units, including courses listed above. Courses used to satisfy requirements 1 through 5 must be taken for grades, unless they are only offered pass/fail.

EE Medical Engineering Track Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
EE 55	Mathematics of Electrical Engineering	12	-	-
EE/APh 40	Physics of Electrical Engineering	-	9	-
EE 44	Deterministic Analysis of Systems and Circuits	12	-	-
EE 45	Electronics Systems and Laboratory	-	-	12
EE/CS 10ab	Introduction to Digital Logic and Embedded Systems	-	6	6
Ma 2	Differential Equations	9	-	-
Ph 2 ab	Sophomore Physics	9	9	-
	EE Electives[2]	-	-	9
	Electives	-	-	9
	HSS Electives [1]	-	18	9
	Total	**42**	**42**	**45**
Third Year				
EE 111	Signal-Processing Systems and Transforms	9	-	-
EE 90	Analog Electronics Project Lab	-	-	9
ACM 95 ab	Intro. Methods of Applied Math.	-	12	12
SEC 10	Technical Seminar Presentations	3	-	-
one of SEC 11-13	Written Communication	-	3	-
	EE/MedE Electives[3]	9	9	9
	EE Electives[2]	9	-	-
	Electives	9	9	-
	HSS Electives [1]	9	9	9

	Total	**48**	**42**	**39**
Fourth Year				
EE 80 abc	Senior Thesis	9	9	9
	EE/MedE Electives[3]	9	9	-
	EE Electives[2]	-	9	9
	Electives	9	-	9
	HSS Electives [1]	9	9	9
	Total	**36**	**36**	**36**

[1] See Institute requirements for specific rules regarding humanities and social sciences.
[2] See EE Medical Engineering Track requirement 5 for specific rules regarding EE electives.
[3] See EE Medical Engineering Track requirement 3 for specific rules regarding EE/MedE electives.

This typical program is not specifically required for graduation in the option. Students are expected to work out individual programs suitable to their interests and professional goals in consultation with their advisors.

EE Photonics and Quantum Track Requirements

The Photonics and Quantum track bridges Electrical Engineering and Physics, offering students the chance to learn about the physical principles underlying modern technology. This track focuses on developing devices and systems used in sensing, communications, and information processing—areas where electromagnetic waves are key enablers. In addition to the fundamentals of EE, the curriculum offers training in optics and photonics, quantum mechanics, and the physics of semiconductors and superconductors.

1. Ma 2, EE 2, SEC10, one of SEC 11-13, EE/CS 10ab, EE/APh 40, EE 44, 45, 55, and 111, Ph 12ab, EE 151.
2. Three of ACM 95a, ACM 95b, ACM/IDS 104, or ACM/EE/IDS 116.
3. Specialization course requirement: 27 units within one of the following specializations:
   a. Optics and Photonics: EE/APh 120, EE/APh 123, APh/EE 130, EE 153, APh/EE 131, APh/EE 132, APh/EE 190ab
   b. Quantum Technologies: EE/APh 158, APh/EE 190ab, APh/Ph 138 ab, Ph/APh 137ab, Ph/CS 219abc
   c. Solid-State Physics / Materials / Nanotechnology: EE/APh 180, APh/EE 183, APh 114 abc, APh 119
4. EE 80abc or an advanced course sequence/project with approval of the Undergraduate Option Representative
5. In addition to the above courses, a total of 54 units selected from any EE course excluding EE 99 and including no more than 18 units of APh/EE 9, Ph 12c, Ph 3, Ph125abc, or, with approval of

the Undergraduate Option Representative, any EE-applicable Ph or APh course numbered over 100; 45 of these units must be numbered over 100. Any course listed under the specialization requirement that has not already been used to satisfy that requirement may also be counted toward this requirement.

6. Passing grades must be earned in a total of 486 units, including courses listed above. Courses used to satisfy requirements 1 through 5 must be taken for grades, unless they are only offered pass/fail.

EE Photonics and Quantum Track Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
EE 44	Deterministic Analysis of Systems and Circuits	12	-	-
EE 55	Mathematics of Electrical Engineering	12	-	-
EE/APh 40	Physics of Electrical Engineering	-	9	-
EE 45	Electronics Systems and Laboratory	-	-	12
EE/CS 10ab	Introduction to Digital Logic and Embedded Systems	-	6	6
Ma 2	Differential Equations	9	-	-
Ph 12 ab	Waves, Quantum Physics, and Statistical Mechanics	9	9	-
	EE Electives[2]	-	-	9
	Electives	-	-	9
	HSS Electives [1]	-	18	9
	Total	**42**	**42**	**45**
Third Year				
ACM 95 ab	Intro. Methods of Applied Math.	-	12	12
ACM/EE/IDS 116	Introduction to Probability Models	9	-	-
EE 151	Electromagnetic Engineering	-	-	9
EE 111	Signal-Processing Systems and Transforms	9	-	-

SEC 10	Technical Seminar Presentations	3	-	-
one of SEC 11-13	Written Communication	-	3	-
	EE Photonics and Quantum Specialization3	9	9	9
	EE Electives[2]	-	9	-
	Electives	9	-	-
	HSS Electives [1]	9	9	9
	Total	**48**	**42**	**39**
Fourth Year				
EE 80 abc	Senior Thesis	9	9	9
	EE Electives[2]	18	9	9
	Electives	-	9	9
	HSS Electives 1	9	9	9
	Total	**36**	**36**	**36**

1 See Institute requirements for specific rules regarding humanities and social sciences.

2 See EE Photonics and Quantum Track requirement 5 for specific rules regarding EE electives.

3 See EE Photonics and Quantum Track requirement 3 for specific rules regarding EE Photonics and Quantum Specialization.

This typical program is not specifically required for graduation in the option. Students are expected to work out individual programs suitable to their interests and professional goals in consultation with their advisors.

ENGINEERING AND APPLIED SCIENCE OPTION (EAS)

Aims and Scope

The engineering and applied science (EAS) option offers students the opportunity for study in a wide variety of challenging areas of science and technology by allowing each student to design a customized course of study that has breadth, depth, and rigor similar to the options listed above.

The aim of the EAS option is to prepare students for research and professional practice in an era of rapidly advancing interdisciplinary technology. The program builds on the core curriculum to combine individual depth of experience and competence in a particular chosen engineering specialty, and a strong background in the basic and engineering sciences, with laboratory and design, culminating in a capstone design experience. It strives to develop professional independence, creativity, leadership, and the capacity for continuing

professional and intellectual growth.

The first year of the four-year course of study leading to a Bachelor of Science degree is common for all students of the Institute, although first-year elective subjects are available as an introduction to various aspects of engineering and applied science. At the end of the first year, students who elect the EAS option are assigned advisers as close to their expressed field of interest as possible, and together with their advisers they develop programs of study for the next three years. Beyond the Institute-wide requirements of physics, mathematics, and humanities, the EAS option requires one year of applied and computational mathematics and a prescribed number of units selected from a wide variety of engineering and applied science courses. Engineering design (synthesis), as distinct from analysis, is considered an essential part of every engineer's capability. Advisers will expect students to select a sufficient number of courses that place emphasis on design.

Any student in the EAS option whose grade-point average is less than 1.9 at the end of the academic year in the subjects listed in the option requirements may be refused permission to continue to work in the EAS option.

EAS Option Requirements

Students who have elected the EAS option must either choose one of the approved areas of concentration (see item 7 below), or by the end of the third term of the sophomore year submit a written proposed customized course of study and obtain approval for it from the EAS option representative.

The course of study must include each of the following elements:

1. Fulfillment of core requirements in differential equations (Ma2 or equivalent); Probability and Statistics (Ma 3 or equivalent); Waves (Ph2a, Ph12a or equivalent), Quantum Mechanics (Ph 2b, Ph 12b, Ch 21a or equivalent); Thermodynamics and Statistical Mechanics (Ph 2c, Ph 12c, ChE 63, ME 11, Ch 21c or equivalent);
2. Demonstration of computer programming competency by taking CS 1, or by taking an approved alternative course, or by passing a placement exam administered by the computer science option by first term of sophomore year.
   a. 27 units of advanced EAS courses with the prefixes Ae, ACM, AM, APh, CE, CS, CDS, EE, ESE, MS, or ME; and
   b. 27 additional units of either advanced EAS courses or advanced science courses offered by the BBE, CCE, GPS, or PMA divisions.
   c. 9 units of laboratory courses taken from the following list: APh 77 bc, Ae/APh 104 bc, CE 180, CS/CNS 171,174, EE 45, 53, EE 90, EE 91, MS 90, MS 125, ME 72 ab, ME 50 ab, ME 90 bc; and
   d. 9 units of additional laboratory courses either from the list in 3a or from EAS courses with the word "laboratory" in the title, but excluding those courses for which first-year laboratory credit is allowed.

3. ACM 95 ab or Ma 108 abc or Ma 109 abc. None of these course sequences may be taken pass/fail.
4. SEC 10 or equivalent; one of SEC 11, SEC 12, or SEC 13 or equivalent.
5. Courses used to satisfy requirements 1–5 above must also satisfy a depth requirement, which must be met by a customized schedule of requirements that is rigorous, has both breadth and depth, and that includes a senior thesis or capstone design project, such as, but not restricted to, EE 80 abc, CS 80 abc, ME 90 abc, or two terms ofEE 91 ab. The student must submit a written proposal justifying their course selections, and obtain the approval of, the EAS option representative by the end of the third term of the sophomore year.
6. At least 117 units of EAS courses not including those used to satisfy requirements 4, 5, and 6 above.
7. The customized schedule of requirements described in 7 shall include a major design experience.
8. Passing grades must be earned in at least 486 units, including those listed in requirements 1–8 above.

ENGLISH OPTION AND MINOR (EN)

Aims and Scope

The option in English provides students with a broad and intensive education in the rich traditions of literature in English from the Middle Ages to the present day, with a particular emphasis on British and American writing. The English faculty expects undergraduate option students to become familiar with a range of literary forms, genres, and styles of expression; to understand how authors and texts can be shaped by historical contexts; to appreciate differences in literary expression across time periods and national traditions; to develop critical reading skills through analysis and interpretation of literary texts; and to become effective writers in matters of style, organization, and interpretive argument.

During the senior year, and typically in the first two terms, English option students enroll in En 99 ab (Senior Tutorial for English Majors) with a faculty member chosen by mutual agreement. The first part of this sequence must begin in fall term. The Senior Tutorial introduces students to advanced methods in literary research and analysis and provides an important means for assessing the progress of English option students in the rigorous study of literary texts and contexts. Students research, write, and revise a 25-30 page paper on a topic in British or American literature; En 99 a is primarily a research term, and En 99 b is primarily a writing term. Both terms involve regular tutorial consultation with the faculty instructor. English option students should begin considering a senior thesis topic in the third term of their junior year in consultation with the option representative or option adviser.

In addition to the Senior Tutorial, the English option requires nine courses. All English option students are assigned an adviser who will help select courses best suited to their needs and interests, including where appropriate a limited number of courses in related fields such

as history, visual culture, creative writing, and literature other than British and American. Students should consult their option adviser in advance of registration for each term. All courses counted toward the option must be taken for grades except for a first-year humanities course in English when taken in the first two quarters of a first-year student's first year.

Most students pursue English as a second option. The emphasis on writing and on critical reading helps students develop communication skills that can enhance their careers as scientists, engineers, and medical professionals. The English option also provides excellent preparation for those seeking careers in law, business, and administration, and in any field that involves extensive communication.

En Option Requirements

1. En 99 ab.
2. 81 additional units of English courses numbered 99 and above. Up to nine units of first-year humanities in English (courses cross-listed Hum/En numbered 60 or below) and/or up to nine units of En 98 may be substituted for up to 18 of the remaining English units. Students may also substitute courses in foreign literature (in the original or in translation) and/or, with authorization of the adviser, related humanities courses numbered above 99, for up to 18 of the remaining English units. Students may also substitute either En 85 or 86, courses in foreign literature (in the original or in translation), and/or, with authorization of the adviser, related humanities courses numbered above 99, for up to 18 of the remaining English units.
3. 54 additional units of science, mathematics, and engineering courses. This requirement cannot be satisfied by courses listed as satisfying the introductory laboratory requirement or by a course with a number less than 10.
4. Passing grades must be earned in a total of 486 units, including the courses listed above.

English Minor Requirements

The English minor is designed for students who want to pursue concentrated study in English and/or American literature, without the extensive course work and the senior thesis required by the English option.

English minors must take 72 units of English courses. These units may include one first-year humanities course; they may also include one directed reading course (En 98). Students wishing to do a minor in English must declare a minor with the English option representative. All courses to be counted toward the option in English must be taken for grades except for a first-year humanities course in English when taken in the first two quarters of a first-year student's first year. Students completing the English minor requirements will have the phrase ”minor in English” added to their transcripts.

1. 72 units of English courses numbered 99 or above.

2. Nine units of first-year humanities in English (courses cross-listed Hum/En numbered 60 or below) may be substitute for any nine of the 72 units required for the minor.
3. Nine units of En 98 may be substituted for any nine of the 72 units required for the minor.
4. Nine units of En 85 or 86 may be substituted for any nine of the 72 units required for the minor.

Courses used to complete the English minor may not be used to satisfy the requirements of another option or minor. However, these courses may be used to satisfy core Institute requirements in the humanities.

ENVIRONMENTAL SCIENCE AND ENGINEERING OPTION AND MINOR (ESE)

Aims and Scope

The ESE major is intended to train students in the environmental sciences, to pursue careers in academia, the public sector, or the private sector. The major can be pursued along two tracks: environmental physics and environmental chemistry. These tracks have separate course requirements and emphases, but at their hearts provide fundamental training in core scientific disciplines, with specialization in applications to the environmental and climate sciences. The two tracks share a sophomore year that continues the Core Curriculum's training in mathematics and physics. Each track requires a laboratory component and training in data analysis and statistics. All ESE majors must take three broad-based classes (ESE 101, 102, and 103) providing introductions to atmospheric and oceanic physics as well as marine and terrestrial biogeochemistry. The physics and chemistry tracks initially parallel their respective majors in the core disciplines. However, there are fewer required classes in the ESE major to enable students to design a curriculum that emphasizes the environmental sciences, after training in a core discipline. A total of 212 units are required for the major, leaving approximately nine classes of free choice outside the major and the core.

Requirements for all ESE Majors, regardless of "Track"

- Ma 2.
- Ph 2a OR Ph12a.
- Training in data analysis and statistics: BE/Bi 103ab OR Ph 20 and Ph 21 OR ChE 15 and BE/Bi 103b.
- ESE 101, ESE 102, ESE 103. If students have taken ESE 1 then they can petition to not have either ESE 101 or ESE 103.
- Science Writing Requirement: Ch 91 OR Ph 70.
- Oral Presentation Requirement: Ge109 OR Ph 70 OR Ch 90.
- ESE 91. Senior thesis (Optional).

Chemistry Track Requirements:

- Ch 21ab, Ch 41ab, ESE/Ge 142, Ge/ESE 143, ESE/Ge/Ch 171.
- Laboratory Requirement: Ch/ChE 9 OR Ch 4a; AND Ch 15.
- At least 77 units of electives, with a maximum of 2 additional lab classes. These courses are to be chosen by the student with approval by the Option Representative or their assigned surrogate. It is expected that the electives will span a range of options and constitute a coherent program in the Environmental Sciences.

Physics Track Requirements:

- Ph 12bc, Ph 106ab, ACM 95ab, ME 11c, ESE 130.
- Laboratory Requirement: Ph 6.
- At least 2 of the following 4 courses: ME/CE/Ge/ESE 146, ESE 131, ESE 133, ME 119.
- At least 77 units of electives. These courses are to be chosen by the student with approval by the Option Representative or their assigned surrogate. It is expected that the electives will span a range of options and constitute a coherent program in the Environmental Sciences.

Biology Track Requirements:

- ESE/Bio 166, 168, and 178.
- Ch 41ab.
- At least 2 of the following 4 courses: Bi 8, Bi 9, Bi 10, Bi/Ch 110.
- At least 9 units of laboratory instruction selected from the following: Bi 10, Ch 7, Ch 8, Ch 15, Ge 116, Ge 120a, Ge 120b.
- At least 77 units of electives. These courses are to be chosen by the student with approval by the Option Representative or their assigned surrogate. It is expected that the electives will span a range of options and constitute a coherent program in the Environmental Sciences.

ESE Typical Course Schedules

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
Ma 2a	Differential Equations	9	-	-
ESE 102	Earth's Oceans	9	-	-
Ch 41ab	Organic Chemistry	9	9	-
Ch 4a	Synthesis and Analysis of Organic and Inorganic Compounds	-	9	-
ChE 15	Introduction to Chemical Engineering Computation	-	-	10

Ph 2a	Waves, Quantum Mechanics, and Statistical Physics	9	-	-
ESE 103	Earth's Biogeochemical Cycles	-	9	-
	Electives	-	-	18
	Total	**36**	**27**	**28**
Third Year				
ESE 101	Earth's Atmosphere	9	-	-
ESE/Ge 142	Aquatic Chemistry of Natural Waters	-	-	9
ChE 15	Introduction to Chemical Engineering Computation	9	-	-
BE/Bi 103b	Statistical Inference in the Biological Sciences	-	9	-
ESE/Ge/Ch 171	Atmospheric Chemistry I	-	-	9
Ge/ESE 143	Organic Chemistry	-	9	-
Ch/ChE 91	Scientific Writing	-	-	9
	Electives	-	9	-
Ch 21ab	Physical Chemistry	9	9	-
	Total	**27**	**36**	**27**
Fourth Year				
	Electives	9	9	9
	Electives	9	9	9
ESE 90	Undergraduate Laboratory Research in Environmental Science and Engineering	9	9	-
ESE 91	Sr. Thesis	-	-	9
	Total	**27**	**27**	**27**

Environmental Science And Engineering Minor (ESE)
The ESE minor is intended to supplement one of Caltech's undergraduate degrees. It is designed for students who wish to broaden their studies beyond their major to include environmental science and engineering. Students completing the ESE minor requirements will have the phrase "minor in environmental science and engineering" added to their transcripts.

ESE Minor Requirements

1. Complete 27 units of ESE 1, 101, 102, or 103
2. Complete 27 additional units of ESE courses (which may include up to 18 units of research under ESE 90, including the required written report).

Except for research courses, all ESE courses to be applied to fulfill the minor requirements must be taken for grades, and students must maintain a minimum grade average of B- in this ESE coursework. Courses that are used to satisfy the ESE minor requirements cannot be used to satisfy course requirements in the major.

GEOLOGICAL AND PLANETARY SCIENCES OPTION (GPS) (GEOLOGY, GEOBIOLOGY, GEOCHEMISTRY, GEOPHYSICS, PLANETARY SCIENCE) AND MINOR

Aims and Scope

The aim of the undergraduate program is to provide thorough training in the geological and planetary sciences and, wherever possible, to integrate these studies with courses in mathematics, physics, chemistry, and biology taken during the student's earlier years at the Institute. Active involvement in research, particularly during the summer, is encouraged. For geologists, field work is important because it provides first hand experience with geological phenomena that is challenging to completely explain or to fully understand solely from classroom or laboratory treatment. We offer a major in Geological and Planetary Sciences (GPS) that involves a number of core courses and various electives. We also provide information below on more focused tracks in each of the options, such that you can be awarded a major in GPS with a stated track on the transcript. These tracks are offered in geology, geobiology, geochemistry, geophysics, and planetary science. Electives permit students to follow lines of special interest in related scientific and engineering fields. Those who do well in the basic sciences and at the same time have a compelling curiosity about the earth, climate, and the other planets are likely to find these options of interest, especially if they enjoy grappling with complex, interdisciplinary problems. Many students majoring in the earth and planetary sciences pursue further training at the graduate level, while others take jobs that leverage a strong background in earth science including opportunities in sustainability, risk assessment, and climate policy.

For those students with an interest in geobiology, there are options to either be associated with the Biology and Biological Engineering or the GPS division. This association formally affects some of the course requirements that are needed to satisfy the undergraduate degree. Additionally, a students' affiliation with one division or another is likely to significantly shape their choice of elective courses and potentially research opportunities. We suggest that any interested students discuss this choice with their adviser and/or contact the option representative in the GPS geobiology option.

It is strongly recommended that students start the GPS major with the Ge 11 sequence in the sophomore year. Because Ge 120 ab may not be offered every year, students in the geology track may also need to take Ge 106 and Ge 120 a in winter and spring term of their sophomore year in order to prepare for Ge 120 b the following summer.

Suggestions of elective courses that fulfill degree requirements are listed below, and include some 200-level courses. While these courses are primarily intended for graduate students, advanced undergraduates may enroll with permission of the instructor.

GPS Double Majors

For students simultaneously pursuing a degree in a second option, courses taken as required courses for that option can also be counted as Ge electives where appropriate. However, courses that count toward the electives requirement in the other option cannot simultaneously be counted toward satisfying the elective requirement in GPS.

GPS Undergraduate Degree Requirements

The following core courses are required for all GPS option tracks:

1. Ge 1 or Ge 11a
2. Ge 11a, 11b, 11c, 11d
3. A writing class, (at least three units)
4. An oral presentation class (at least three units)
5. Ma 2
6. Ma 3 or Ge/Ay 117
7. Ph 2a or Ph 12a
8. One of: Ph 2b, Ph 12b, Ph 2c, Ph 12c

Courses that cover both writing and presentation, e.g. En/Wr 84, that are at least 6 units may be counted towards requirements (3) and (4) above. Students that elect to use Ge 11a for requirement (1) may substitute an elective for Ge 11a in requirement (2). Assuming 3 units each for requirements (3) and (4), the total core requirements totals 87 units; a writing course such as En/Wr 84 (9 units) would increase this to 90 units.

The GPS Major (no special track)

In addition to the core requirements stated above, the student may design a course of study, in consultation with their adviser, that satisfies the following requirements:

63 units of advanced Science, Mathematics, or Engineering outside GPS.

72 units of GPS elective coursework. A maximum of 9 credits each of Ge 136 and Ge 40/41 can be used to fulfill this requirement. The combination of the core requirements and the 135 units of GPS major requirements should total no less than 222 units.

Geology Track
In addition to the core requirements stated above, a GPS major with a Geology track must include:

1. Either ACM 95ab or a full-year chemistry sequence, Ch 41abc or Ch 21abc
2. Ge 106
3. Ge 114 ab
4. Ge 115 ab
5. Ge 120 a
6. Ge 112 or Ge/ESE 125
7. An external geology field camp during the summer following sophomore or junior year, chosen in consultation with advisor, and with the student's participation funded by Caltech.
8. Additional elective courses in Ge or ESE to bring the total number of units to 220, including the core classes. A maximum of 9 credits each of Ge 136 and Ge 40/41 can be used to fulfill this requirement.

Typical Course Schedules

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
Ma 2 & 3	Sophomore mathematics	9	9	-
Ph 2 a & c	Sophomore physics	9	-	9
Ge 11 abc	Intro. To Earth and Planetary Sci.	9	9	9
Ge 106	Intro. to Structural Geology	-	9	-
Ge 120a	Field Geology Intro.	-	-	9
	HSS electives	9	9	9
	Total	**36**	**36**	**36**
Summer				
	External Geology Field Camp	-	-	15
Third year				
ACM 95 ab	Intro. Methods of Applied Math.	-	12	12
Ge 112	Sedimentology and Stratigraphy	12	-	-
Ge 114 ab	Mineralogy	9	-	-

Ge 115 a	Petrology and Petrography	-	9	-
Ge 111 ab	Applied Geophysics	-	6	9
	HSS electives	9	9	9
	Total	**30**	**36**	**30**
Fourth Year				
	Geology electives	9	9	9
Ge 115 b	Petrology and Petrography	-	9	-
	HSS electives	9	9	9
	Scientific Writing	-	-	3
SEC 10	Oral Presentation	-	-	3
	Total	**18**	**27**	**24**

Geobiology Track
In addition to the core requirements stated above, a GPS major with a Geobiology track must include the following courses. Similar to En/Wr 84, Bi 24 satisfies both the writing and speaking requirements, (3) and (4), above. Additionally, for the geobiology track, Bi/CNS/NB 195 or Be/Bi 103a can be substituted for the Ma 3 or Ge/Ay 117 courses for requirement (6) above.

1. Ch 41abc
2. Ch/Bi 110a or Ch/Bi 110b
3. Bi 8 and Bi 9
4. At least 9 units of laboratory instruction selected from the following: Bi 10, Ch 7, Ch 8, Ch 15, Ge 116, Ge 120a, Ge 120b
5. Any 6 electives from the geobiology core courses: Bi 117, Bi 122, ESE/Bi 166, ESE/Bi 168, Ge/ESE/Bi 178, Ge 112, Ge/ESE 143, Ge 124a, Ge 124b
6. 9 additional unit in Ge, Bi, Ch, or ESE

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
Ma 2 & other	Sophomore mathematics	9	9	-
Ph 2 a, c	Sophomore physics	9	-	9
Ge 11 abc	Intro. to Earth and Planetary Sci.	9	9	9
Bi/BE 24	Writing and oral presentation	-	-	6

Bi 8	Introduction to Molecular Biology	-	9	-
Bi 9	Cell Biology	-	-	9
Bi 10	Cell Biology Laboratory	-	-	6
	HSS electives	9	9	9
	Total	**36**	**36**	**48**
Third Year				
Ch/Bi 110a	Intro. to Biochemistry	12	-	-
Ge 124 ab	Paleomagnetism	-	-	15
	Scientific Writing	-	3	-
Ch 41 abc	Organic Chemistry	9	9	9
	HSS electives	9	9	9
	Geobiology electives	-	9	-
	Total	**30**	**30**	**42**
Fourth Year				
ESE/Bi 166	Microbial Physiology	9	-	-
ESE/Bi 168	Microbial Metabolic Diversity	-	9	-
Ge/ESE/Bi 178	Microbial Ecology	-	-	9
Ge 143	Organic Geochemistry	-	-	9
Bi 122	Genetics	9	-	-
Ge 112	Sedimentology and Stratigraphy	12	-	-
Ge 116	Analytical Laboratory Techniques	-	9	-
	HSS electives	9	9	9
	Geobiology electives	-	-	9
	Total	**39**	**27**	**36**

Geochemistry Track
In to addition the core requirements stated above, a GPS major with a Geochemistry track must include:

1. ACM 95ab or Ch 41 abc or Ch 21 abc
2. 3 GPS electives with a chemical component from the following list: Ge 114ab, Ge 116, Ge 140a, Ge 140b, Ge/ESE 140c, Ch 21a,

Ch 41a, ESE/Ge/Ch 171, Ge/ESE 143, Ge/ESE 149

3. 81 additional units of elective courses in Ch, ESE, Ge, APh, or MS. These courses may be selected from: Ch 4ab, Ch 5ab, Ch 6ab, Ch 7, Ch 8, Ch/ChE 9, Ch 14, Ch 15, Ch 21bc, Ch 41bc, Ch 102, ChE 63ab, ESE 103, ESE/Ge 142, Ge/ESE 154, ESE/Ge/Ch 171, ESE/Ge/Ch 172, ESE/Ch 176, ESE/Ch 177, Ge 40, Ge 106, Ge 112, Ge 115ab, Ge 120ab, Ge/Ch 127, Ge/Ch 128, Ge/AY 132, Ge/ESE 143, Ge/ESE 129, Ge 191, Ge 212, Ge 214, Ge 215, Ge 217, Ge 218, Ge 219, APh 17abc, APh/MS/ME 105abc, MS 115, MS 125, MS 131, MS 133, MS 142, MS/ME 161. A maximum of 9 credits each of Ge 136 and Ge 40/41 can be used to fulfill this requirement.

Students may petition the Geochemistry option representative to use courses not listed above to satisfy requirements (2) and (3).

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
Ge 11 abc	Intro. to Earth and Planetary Sci.	9	9	9
	Scientific Writing	-	-	3
Ge 109	Oral Presentation (GeCh option)	-	-	6
	Geochemistry core or electives	9	9	9
Ph 2 ab	Sophomore Physics	9	9	-
Ma 2 & other	Sophomore Mathematics	9	9	-
	HSS electives	9	9	9
	Total	**45**	**45**	**33**
Third Year				
ACM 95 ab	Intro. Methods of Applied Math.	-	12	12
	HSS electives	9	9	9
	Geochemistry core or electives	18	18	18
	Total	**27**	**39**	**39**
Fourth Year				
	HSS electives	9	9	9

	Geochemistry electives	9	9	9
	Total	**18**	**18**	**18**

Geophysics Track
In addition to the core requirements stated above, a GPS major with a Geophysics track must include:

1. ACM 95ab
2. One of the following courses that was not already used to satisfy the core GPS degree requirements: Ph 2b, Ph 12b, Ph 2c, Ph 12c, ME 11a, APh 17a, Ch 21c, Ch 25
3. 45 units of courses in advanced Science, Mathematics, or Engineering outside of GPS
4. 51 units of GePh electives, including but not limited to: Ge 111a and Ge 111b (15 units total), Ge 160a, Ge 161-168, Ge 166, Ge 174, Ge 177, Ge 261, Ge 263, Ge 266ab, Ge 271. A maximum of 9 credits each of GE 136 and GE 40/41 can be used to fulfill this requirement.

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
Ge 11 abc	Intro. to Earth and Planetary Sciences	9	9	9
	Scientific Writing	-	-	3
SEC 10	Oral Presentation	-	-	3
Ph 2 abc	Sophomore Physics	9	9	9
Ma 2 & Ma 3	Sophomore Mathematics	9	9	-
	HSS electives	9	9	9
	Total	**36**	**36**	**33**
Third Year				
ACM 95 ab	Intro. to Methods of Applied Math.	-	12	12
	Advanced Science Electives	9	9	9
	HSS electives	9	9	9
Ge 111 ab	Applied Geophysics Seminar	-	6	9
Ge 11 d	Geophysics	-	9	-

	Total	**18**	**45**	**39**
Fourth Year				
	Geophysics electives	18	18	9
	HSS electives	9	9	9
	Total	**27**	**27**	**18**

Planetary Science Track
In addition to the core requirements stated above, a GPS major with a Planetary Science track must include:

1. ACM 95ab
2. One of the following courses that was not already used to satisfy the core GPS degree requirements: Ph 2b, Ph 12b, Ph 2c, Ph 12c, ME 11a, APh 17a, Ch 21c, Ch 25
3. 45 units of courses in advanced Science, Mathematics, or Engineering outside of GPS
4. 54 units of GPS coursework that includes 4 courses (36 units) chosen from the following: Ge 107, Ge 128, Ge 131, Ge 132, Ge 133, Ge 137, Ge 150, Ge 151, Ge 157c, Ge 159. A maximum of 9 credits each of Ge 136 and Ge 40/41 can be used to fulfill this requirement

We recommend the students consult with their advisers regarding courses that are used to satisfy requirement (3).

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
Ge 11 abc	Intro. to Earth and Planetary Sci.	9	9	9
	Scientific Writing	-	-	3
Ph 2 abc	Sophomore Physics	9	9	9
Ma 2, 3	Sophomore Mathematics	9	9	-
	HSS electives	9	9	9
	Total	**36**	**36**	**30**
Third Year				
ACM 95 ab	Intro. Methods of Applied Math.	-	12	12
	HSS electives	9	9	9

	Advanced science	9	9	9
	Planetary science	9	9	9
	Total	**27**	**39**	**39**
Fourth Year				
	HSS electives	9	9	9
	Planetary science	9	9	9
	Additional advanced/planetary science	9	9	9
	Total	**27**	**27**	**27**

GPS Minor
The minors in the GPS Division are intended for non-GPS undergraduates to supplement a major degree with knowledge of earth and planetary science. The requirements for the minor are as follows:

1. Ge 11a
2. Select two of the following courses: Ge 11b, Ge 11c, Ge 11d
3. 27 units of 100-level or higher GPS courses, excluding Ge 109. A maximum of 9 credits of Ge 136 can be used to fulfill this requirement

If the courses selected for requirement (3) above are sufficiently focused in one of the GPS options, students may opt to include a track on their transcript (e.g. Minor in GPS with [option] track). Minor tracks are possible in Geobiology, Geochemistry, Geology, Geophysics, and Planetary Sciences. The courses selected for (3) must be approved by the appropriate option representative in the division. Any 27 units that satisfy (3) may be used to satisfy the GPS minor, regardless of focus.

HISTORY OPTION AND MINOR (H)

Aims and Scope
Students who choose the history option will learn how to *do* history—how to think critically about past societies and their development, how to read evidence closely, and how to express arguments in writing. With the guidance of a faculty adviser in history, students taking the option will explore the range of human experience in the realms of politics, culture, religion, and economics, as well as science and technology. They will learn both to challenge and revise existing historical narratives and question their own ideas and assumptions about the past. Students will develop the writing skills that will enable them to use historical sources to make effective arguments, and they will receive extensive feedback on their writing

from their adviser and from other faculty members.

The history option thus provides science and engineering students with an important supplement to the scientific training and technical skills they acquire in other courses and options. It will help them to understand the world of human beings and human behavior outside of science with which they will interact and which their scientific work will affect; to set themselves and their work as scientists and engineers in this wider context; and to communicate what they are doing to a wider public as well as to their colleagues. In addition, it offers excellent preparation for careers in business, administration, law, journalism, or public affairs, as well as a solid foundation for graduate work in history.

History majors must take at least 99 units of history courses (which may include a first-year humanities course in history) during their four years as undergraduates. Of these, 27 must be in the senior tutorial (H 99 abc). All courses to be counted toward the history option must be taken for grades except for a first-year humanities course in history when taken in the first two quarters of a first-year student's first year. History majors may also choose to take one term of H 98, an individual program of directed reading that will allow students to explore areas of history not covered by regular courses.

Each history major will choose an area of concentration in consultation with their adviser and the history option representative. These areas might include, but are not restricted to, fields such as ancient history, medieval Europe, early-modern Europe, modern Europe, Russian history, American history pre- 1865, American history post-1865, early-modern history of science, modern history of science, or economic history. A student must take 63 units of courses in this area; 27 of these units must be in the senior tutorial H 99 abc.

In the senior tutorial, students will have the opportunity over the course of three terms to explore in depth an historical subject of particular interest to them, while working one-on-one with a member of the history faculty. They will learn how to carry out historical research, in libraries as well as on-line, and engage critically with both primary and secondary historical sources. Finally, they will learn, under the direct supervision of their faculty mentor, to organize and to write an extensive research paper, of at least 30 pages, that makes an original, clear and persuasive scholarly argument. In H 99a, students will carry out general research in their area of interest, and identify the specific topic on which they wish to write. In H 99b they will learn to frame a research question, carry out independently the necessary research to answer it, and generate an outline of their paper. In H 99c they will write and revise their paper in response to feedback from their faculty mentor.

Each student must take the remaining 36 units of history required by the option in areas other than the area of concentration, again defined in consultation with their adviser and the history option representative. These areas may include not only fields within the discipline of history proper, but also useful cognate fields such as economics, political science, anthropology, law, English, or a foreign language.

A student considering the history option when they come to Caltech will be well advised to take a first-year humanities course in history (courses cross-listed Hum/H numbered 60 or below). In the sophomore year, the student should take upper-level history courses, but this is also a good time to pursue the study of English or philosophy, to begin or continue a foreign language, and to do introductory work in the social sciences. A student will normally make a commitment to an area of concentration early in the junior year. At the beginning of the senior year, a history major will enroll in H 99 abc with a faculty member in their area of concentration.

H Option Requirements

1. H 99 abc.
2. 72 additional units of history courses numbered 99 or above. Up to nine units of first-year humanities in history (courses cross-listed Hum/H numbered 60 or below) and/or up to nine units of H 98 may be substituted for up to 18 of these units.
3. 63 of the total history units, including H 99 abc, must be in an area of concentration, as defined in consultation with the student's adviser and the history option representative.
4. 36 of the total history units must be in an area or areas other than the area of concentration, as defined in consultation with the student's adviser and the history option representative. H 99 abc may not be used to fulfill this requirement.
5. 54 additional units of science, mathematics, and engineering courses. This requirement cannot be satisfied by courses listed as satisfying the introductory laboratory requirement or by menu courses.
6. Three units of oral communication. En/Wr 84 satisfies this requirement, as do oral communication courses offered by other options.
7. Passing grades must be earned in a total of 486 units, including the courses listed above.

Courses used to complete the history option under categories 1, 2, or 3 above may not be used to satisfy the requirements of another option or minor.

H Minor Requirements

The history minor is designed for students who want to pursue concentrated study in history without the extensive course work and the senior thesis required by the history option.

History minors must take 72 units of history courses. These units may include one first-year humanities course; they may also include one directed reading course (H 98). All courses to be counted toward the history minor must be taken for grades except for a first-year humanities course in history when taken in the first two quarters of a first-year student's first year. Students wishing to do a minor in history must declare a minor with the history option representative. Students completing the history minor requirements will have the phrase "minor in history" added to their transcripts.

1. 72 units of history courses numbered 99 or above.
2. Nine units of first-year humanities in history (courses cross listed Hum/H numbered 60 or below) may be substituted for
3. any nine of the 72 units required for the minor.
4. Nine units of H 98 may be substituted for any nine of the 72
5. units required for the minor.

Students cannot use history minor requirements to satisfy a different option or minor.

HISTORY AND PHILOSOPHY OF SCIENCE OPTION AND MINOR (HPS)

Aims and Scope

The history and philosophy of science option (HPS) provides students the opportunity to explore the historical evolution of the sciences and the philosophical perspectives that inform them, as well as the dynamics between science, technology, and other human endeavors.

HPS courses in history help students learn about the origins of experimental practice; the social and institutional contexts of science; the origins and applications of quantitative methods; specific developments since antiquity in physics, biology, chemistry, geography and cartography, medicine; and biographical and comparative studies in these fields. HPS courses in philosophy deal with issues in causation and explanation; the foundations of probability and statistical inference; and philosophical problems in particular fields such as biology, mathematics, medicine, neuroscience, and physics. In their coursework, students receive regular feedback from the faculty on their research, writing, and presentation skills. They have the opportunity to carry out independent research, especially in their thesis work, and present their findings in a seminar setting.

This option thus aims to give students a broad, basic understanding of how science is practiced and how that practice has changed over time. Students learn to address questions such as: To what extent was the scientific revolution revolutionary? What is a scientific explanation and how do scientists go about constructing and justifying one? How have conceptions of scientific experimentation changed? What are the ethical issues raised by experimentation with human or animal subjects? How has relativity theory changed our conceptions of space and time? The option is designed to complement the regular science curriculum at Caltech, offering students the opportunity to enlarge upon, and to contextualize, the strong technical skills they acquire in other courses and options.

Because of its emphasis on essay writing and formulating complex philosophical and historical arguments, our curriculum provides training in writing and communication skills that are increasingly vital today. The HPS option provides excellent preparation for students going into law, business, medicine, science journalism and public affairs, and it also prepares students for graduate work in the history

and/or philosophy of science.

HPS Option Requirements

1. Hum/H/HPS 18; HPS 102 ab; HPS/Pl 120; and HPS 103 (one quarter). (HPS 102 b fulfills the Institute science writing requirement.)
2. One advanced course in the history of science, chosen from HPS/H offerings with a course number of 98 or higher; one advanced course in philosophy of science, chosen from HPS/Pl offerings with a course number of 98 or higher; and any four courses in HPS. (No more than 9 units of HPS 98 may be counted towards the HPS major.)
3. 45 units of courses in science, mathematics, and engineering. This requirement cannot be satisfied by courses listed as satisfying the introductory laboratory requirement or by a course with a number less than 10.
4. Passing grades must be earned in a total of 486 units, including all courses used to satisfy the above requirements.

Courses used to complete the history and philosophy of science option under categories 1, 2, or 3 above may not be used to satisfy the requirements of another option or minor.

We recommend that students intending to follow the HPS option take Hum/H/HPS 18, Introduction to History of Science, as one of their first-year humanities courses. Students making the decision to follow this option in their sophomore year should take Hum/H/HPS 18 and HPS/Pl 120, Introduction to Philosophy of Science, as early as possible in that year. Students may also enter the option in their junior year if they can complete the option's requirements in time for graduation. Please also note the following:

Not all required courses are offered each term; students should consult the current catalog to determine which terms required courses are being offered, and should construct their course plan for the year accordingly.

We encourage students to choose their advanced social science electives from among courses that will enlarge their perspective on topics related to HPS (for example, Ec 118, Ec/SS 128, Ec 129, Ec 130, PSY 101, PSY 115, PSY 125, PSY 130, PS 120, PS 121, PS 122, An 22).

HPS 102ab, the Senior Research Seminar, may be taken in any two consecutive terms in the Senior year. Students should coordinate with their HPS adviser in determining their course schedule.

HPS Typical Course Schedule

First Year

It is recommended that students intending to follow the HPS option take Hum/H/HPS 18 as one of their first-year humanities courses.

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
HPS 18[1]	Introduction to History of Science	9	-	-
HPS/PI 120[1]	Introduction to Philosophy of Science	-	9	-
	Advanced HPS/history	-	-	9
HPS 103	Public Lecture Series	1	1	1
	Menu course	-	-	9
Ec 11 or PS 12	Introductory Social Science	9	-	-
	Other electives	27	36	27
	Total	**46**	**46**	**46**
Third Year				
HPS 103	Public Lecture Series	1	1	1
	Advanced HPS/history	-	9	9
	Advanced HPS/philosophy	9	9	9
	Science, math, engineering	9	9	9
	Advanced social science[2]	9	-	-
	Other electives	18	18	18
	Total	**46**	**46**	**46**
Fourth Year				
HPS 103	Public Lecture Series	1	1	1
HPS 102 ab[3]	Senior Research Seminar	-	12	12
	Advanced social science[2]	9	-	-
	Science, math, engineering	9	9	9
	Other electives	27	18	18
	Total	**46**	**40**	**40**

[1] Not all required courses are offered each term; students should consult the current catalog to determine which terms required courses are being offered, and they should construct their course plan for the year accordingly.

[2] We encourage students to choose their advanced social science electives from among courses that will enlarge their perspective on topics related to HPS (for example, Ec 118, Ec/SS 128, Ec 129, Ec 130, PSY 101, PSY 115, PSY 125, PSY 130, PS 120, PS 121, PS 122, An 22)

[3] Finally, HPS 102 ab, Senior Research Seminar, may be taken in any two consecutive terms in the senior year. Students should coordinate with their HPS adviser in determining their course schedule.

HPS Minor Requirements

The minor in HPS is designed for students who want to pursue concentrated study in the field without the extensive course work and the senior thesis required by the HPS option.

HPS minors must complete 72 units of HPS courses. First-year Humanities courses other than Hum/H/HPS 18 may not be counted towards an HPS minor. Students wishing to do a minor in HPS must declare a minor with the HPS option representative. Those completing the HPS minor requirements will have the phrase "minor in History and Philosophy of Science" added to their transcripts.

1. 72 units of HPS courses numbered 99 or above.
2. 9 units of HPS 98 may be substituted for any 9 of the 72 unit required for the minor.
3. 9 units of Hum/H/HPS 18 may be substituted for any 9 of the 72 units required for the minor.

Students cannot use HPS minor requirements to satisfy a different option or minor.

INFORMATION AND DATA SCIENCES OPTION AND MINOR (IDS)

Aims and Scope

The information and data sciences are concerned with the acquisition, storage, communication, processing, and analysis of data. These intellectual activities have a long history, and Caltech has traditionally occupied a position of strength with faculty spread out across applied mathematics, electrical engineering, computer science, mathematics, physics, astronomy, economics, and many others disciplines. In the last decade, there has been a rapid increase in the rate at which data are acquired with the objective of extracting actionable knowledge—in the form of scientific models and predictions, business decisions, and public policies. From a technological perspective, this rapid increase in the availability of data creates numerous challenges in acquisition, storage, and subsequent analysis. More fundamentally, humans cannot deal with such a volume of data directly, and it is increasingly essential that we automate the pipeline of information processing and analysis. All areas of human endeavor are affected: science, medicine, engineering, manufacturing, logistics, the media, entertainment. The range of scenarios that concern a scientist in this domain are very

broad—from situations in which the available data are nearly infinite (big data), to those in which the data are sparse and precious; from situations in which computation is, for all practical purposes, an infinite resource to those in which it is critical to respond rapidly and computation must thus be treated as a precious resource; from situations in which the data are all available at once to those in which they are presented as a stream.

As such, the information and data sciences now draw not just upon traditional areas spanning computer science, applied mathematics, and electrical engineering—signal processing, information and communication theory, control and decision theory, probability and statistics, algorithms—but also a range of new contemporary topics such as machine learning, network science, distributed systems, and neuroscience. The result is an area that is new, fundamentally different that related areas like computer science and statistics, and that is crucial to modern applications in the physical sciences, social sciences, and engineering.

The Information and Data Sciences (IDS) option is unabashedly mathematical, focusing on the foundations of the information and data sciences, across its roots in probability, statistics, linear algebra, and signal processing. These fields all contribute crucial components of data science today. Further, it takes advantage of the interdisciplinary nature of Caltech by including a required set of application courses where students will learn about how data touches science and engineering broadly. The flexibility provided by this sequence allows students to see data science in action in biology, economics, chemistry, and beyond.

In addition to a major, the IDS option offers a minor that focuses on the mathematical foundations of the information and data sciences but recognizes the fact that many students in other majors across campus have a need to supplement their options with practical training in data science.

IDS Option Requirements

1. Computer Science Fundamentals. CS 1 or CS 1X; CS 2; CS 21 or Ma/CS 6c; and CS 38.
2. Mathematical Fundamentals. Ma 2; Ma 3 or Ma/ACM/IDS 140a; Ma 108a; (CS13 or Ma/CS 6a or Ma 121a); (Ma/CS 6b or Ma 121b). The analytical tracks of Ma1bc are strongly recommended.
3. Scientific Fundamentals. 18 units selected from the following courses: BE/Bi 25, BE 153, Bi 8, Bi 9, Bi 117, Ch 21abc, Ch 24, Ch 25, Ch 41abc, Ph 2abc, or Ph 12abc. Advanced 100+ courses in Bi, Ch, or Ph with strong scientific component can be used to satisfy this requirement with approval from the option representative, but cannot simultaneously be used to satisfy the "Applications Elective" requirement or the "Advanced Electives" requirement.
4. Communication Fundamentals. SEC 10; and one of SEC 11-13.
5. Information and Data Science Core Requirements.
    a. Linear Algebra: ACM/IDS 104; ACM 106a.
    b. Probability: ACM/EE/IDS 116.

c. Statistics: IDS/ACM/CS 157.
d. Machine Learning: CMS/CS/CNS/EE/IDS 155 or CS/CNS/EE 156a.
e. Signal Processing: EE/IDS 111 or ACM/EE/IDS 170.
f. Information Theory: EE/IDS 160

6. Applications Electives. At least 18 units from the following list: Ay 119, BE/Bi 103 ab, BE/Bi 205, BEM 106, Bi/CNS/NB 162, Bi/BE/CS 183, CNS/Bi/EE/CS/NB 186, ME/CS/EE 133b, ME/CS/EE 134, EE/CNS/CS 148, Ec/ACM/CS 112, Ec 122, Ec/PS 124, ESE 136, Fs/Ay 3, Fs/Ph 4, Ge/Ay 117, Ge 165, HPS/Pl/CS 110, SS 228. Other courses that include applications of data science may be substituted with approval from the option representative. Courses used to fulfill this requirement may not also be used to fill the any requirement above
7. Advanced Electives. At least 54 units from the following list: IDS courses numbered 100 or above, CS/CNS/EE 156ab, ACM 106b, ACM 95/100ab, CMS/ACM/EE 122, CS 115, Ma 112 ab. Courses used to fulfill this requirement may not also be used to fill the any requirement above.

Courses used to fulfill requirements in the “Applications of Data Science” and “Advanced Electives” requirements cannot be used to fulfill the institute humanities and social sciences requirements.

Units used to fulfill the Institute Core requirements do not count toward any of the option requirements. Pass/fail grading cannot be elected for courses taken to satisfy option requirements. Passing grades must be earned in total of 486 units, including all courses used to satisfy the above requirements.

IDS Double Majors

Students interested in simultaneously pursuing a degree in a second option must fulfill all the requirements of the Information and Data Sciences option. Courses may be used to simultaneously fulfill requirements in both options. However, it is required that students have at least 54 units of ”Advanced Electives” and 18 units of ”Applications of Data Science” that are not simultaneously used for fulfilling a requirement of the second option, i.e., the requirements of the Advanced Electives and the Applications of Data Science sections must be fulfilled using courses that are not simultaneously used for fulfilling a requirement of the second option. Any proposal to replace these courses must be discussed with the option administrator. To enroll in the program, the student should meet and discuss their plans with the option representative. In general, approval is contingent on good academic performance by the student and demonstrated ability for handling the heavier course load.

IDS Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
CS 1	Intro. to Computer Programming	9	-	-
CS 2	Intro. to Programming Methods	-	9	-
CS 38	Algorithms	-	-	9
Ma 2	Differential Equations	9	-	-
Ma 3	Intro. to Probability and Statistics	-	9	-
Ma/CS 6 ab	Intro. to Discrete Methods	9	9	-
ACM/IDS 104	Applied Linear Algebra	9	-	-
	HSS Electives	9	9	9
	Scientific Fundamentals	-	9	9
	Other Electives	-	-	9
	Total	**45**	**45**	**36**
Third Year				
SEC 10	Technical Seminar Presentations	-	3	-
CMS/CS/CNS/EE /IDS 155	Machine Learning & Data Mining	-	12	-
One of SEC 11-13	Written Communication	-	-	3
Ma 108 a	Classical Analysis	9	-	-
EE/IDS 111	Signal-Processing Systems and Transforms	9	-	-
IDS/ACM/CS 157	Statistical Inference	-	-	9
ACM/EE/IDS 116	Intro. to Probability Models	9	-	-
	HSS Electives	9	9	9
	Advanced Electives	9	9	9
	Applications Electives	-	9	-
	Other Electives	-	-	9

	Total	**45**	**42**	**39**
Fourth Year				
ACM/EE 106 a	Intro. Methods of Computational Math.	12	-	-
EE/IDS 160	Fundamentals of Information Transmission and Storage	-	9	-
	Advanced Electives	9	9	9
	Applications Electives	9	9	-
	HSS Electives	9	9	9
	Other Electives	9	9	18
	Total	**48**	**45**	**36**

IDS Advising

Starting in the sophomore year IDS students will be assigned a faculty adviser whom they should meet with regularly, typically once per quarter. Students in the program are advised by faculty interested in the information and data sciences from across the institute. This includes all the CMS faculty, as well as the following faculty that pursue data science-related research and participate in IDS advising: Mike Alvarez, Justin Bois, Fernando Brandao, Jaksa Cvitanic, Frederick Eberhardt, Babak Hassibi, Thomas M. Hutchcroft, Jonathan Katz, Victoria Kostina, Kirby Nielsen, Pietro Perona, Antonio Rangel, Vikram Ravi, Mikhail Shapiro, Mark Simons, Matt Thomson, Zhongwen Zhan. Students seeking an IDS adviser should contact the undergraduate option secretary at academics@cms.caltech.edu.

IDS Minor Requirements

1. Computer Science Fundamentals. CS1 or CS 1X; CS2; CS21 or Ma/CS6c; and CS38.
2. Mathematics Fundamentals. Ma 3 or Ma/ACM/IDS 140a; (CS13 or Ma/CS 6a or Ma 121a).
3. Information and Data Science Core Requirements.
    a. Linear Algebra: ACM/IDS 104.
    b. Probability: ACM/EE/IDS 116.
    c. Statistics: IDS/ACM/CS 157.
    d. Machine learning: CMS/CS/CNS/EE/IDS 155 or CS/CNS/EE 156a.
    e. Signal Processing: EE/IDS 111 or ACM/EE/IDS 170.
4. Applications Electives. At least 9 units from the following list: Ay 119, BE/Bi 103 ab, BE/Bi 205, BEM 106, Bi/CNS/NB 162, Bi/BE/CS 183, CNS/Bi/EE/CS/NB 186, ME/CS/EE133b, ME/CS/EE 134, EE/CNS/CS 148, Ec/ACM/CS 112, Ec 122, Ec/PS 124, ESE 136, Fs/Ay 3, Ge/Ay 117, Ge 165, HPS/Pl/CS 110, SS 228. Other courses that include applications of data science may be substituted with approval from the option

representative.

5. Advanced Electives. At least 9 units from the following list: IDS courses numbered 100 or above, CS/CNS/EE 156ab, ACM 106b, ACM 95/100ab, CMS/ACM/EE 122, CS 115, Ma 112 ab. Courses used to fulfill this requirement may not also be used to fulfill any requirement above.

Courses used to fulfill requirements in the "Applications of Data Science" and "Advanced Electives" requirements cannot be used to fulfill (i) a requirement for another major or minor; or (ii) the institute humanities and social sciences requirements. Any replacement of these courses must be discussed with the option administrator.

Pass/fail grading cannot be elected for courses taken to satisfy option requirements. Courses taken as part of the data science minor are counted toward the total 486 units needed for Institute graduation requirements.

Typical course schedule

A typical course sequence is to take CS 1 during the first year; Ma/CS 6a, Ma 3, CS2 and CS38 during sophomore year; ACM/EE/IDS 116, ACM/IDS 104, CMS/CS/CNS/EE/IDS 155, and IDS/ACM/CS 157 during junior year; and EE/IDS 111 and the elective courses during senior year.

INTERDISCIPLINARY STUDIES PROGRAM OPTION (ISP)

Aims and Scope

The Interdisciplinary Studies Program (ISP) is an undergraduate option that allows the student to create their own scholastic requirements, under faculty supervision, and to pursue positive educational goals that cannot be achieved in any of the other available options. A student's program may include regular Caltech courses, research courses, courses at other schools, and interdisciplinary study courses (item 5, next page). In scope and depth, the program must be comparable to a normal undergraduate program, but it need not include all of the specific courses or groups of courses listed in the formulated Institute option requirements for undergraduates.

The Curriculum Committee, a standing committee of the faculty, has overall responsibility for the program. In addition, each student has their own committee of at least two advisers, two of whom must be professorial faculty. Application material may be obtained at the dean of undergraduate students' office or website.

ISP Administrative Procedures and Guidelines

1. An interested student must recruit at least two professorial faculty members representing at least two different degree-granting options to serve as the ISP faculty committee. Each member of the faculty committee must provide a letter that includes:
    a. Faculty name and department/division, and the discipline they "represent" within the proposed ISP.

   b. Faculty's assessment of the student's ISP proposal, including the proposed degree title, as it relates to that faculty's discipline.
   c. Faculty assessment of whether the student could choose an existing degree-granting option with some acceptable accommodations, rather than create an ISP. That is, does this ISP enable something that could not be accomplished in a single option or major/minor combination.
2. Send the ISP proposal (cover sheet, proposed curriculum, and the aforementioned letters from professorial faculty advisers to the dean of undergraduate students for review and approval.
3. The dean of undergraduate students sends the ISP petition to the Curriculum Committee for review and final approval. This contract includes the agreed-upon content of the student's program and the methods for ascertaining satisfactory progress for those parts of the student's program that are not standard Institute courses. This contract may of course be amended, but any amendments must be approved by the committee of two and the Curriculum Committee. Copies of each student's contract and of all amendments thereto, along with all ISP records for each student and their transcript, are kept in the permanent files of the Registrar's Office. Passing grades must be earned in a total of 486 units.
4. The progress of each student in the ISP is monitored each quarter by the registrar, and any deviations from the terms of the contract are reported to the chair of the Curriculum Committee. Standards for acceptable progress and for satisfactory completion of the terms of the contract are the responsibility of the Curriculum Committee. When the Committee is satisfied that the terms of the contract have been fulfilled by the student, it recommends the student to the faculty for graduation.
5. A plan of study may include special ISP courses to accommodate individual programs of study or special research that falls outside ordinary course offerings. In order that credit be received for an ISP course, a written course contract specifying the work to be accomplished, time schedule for progress reports and completed work, units of credit, and form of grading must be agreed upon by the instructor, the student, and the committee of two, and submitted to the registrar prior to initiating the work in the course. ISP courses are recorded on the student's transcript in the same manner as are other Caltech courses.
6. ISPs are intended for multiyear programs. Accordingly, the Curriculum Committee urges students contemplating an ISP to submit their petition during their second year and will not normally consider such petitions any later than the first term of the student's third year.

MATERIALS SCIENCE OPTION (MS)

Aims and Scope

The aim of the Materials Science option is to prepare students for research, professional practice, or advanced study in a rapidly advancing interdisciplinary field, focusing on the relationships between the properties of materials and their internal structure and how this structure can be controlled. The program builds on the core curriculum to develop analytical competence and use it for individualized research, culminating in a one-year senior thesis. Materials Science students develop professional independence, creativity, leadership, and the skills for continuing professional and intellectual growth. The first year of the four-year course of study leading to a Bachelor of Science degree is common for all students of the Institute, although first-year elective subjects are available as an introduction to various aspects of engineering and applied science. At the end of the first year, students who elect the Materials Science option are assigned advisers appropriate for their expressed field of interest. Together with their advisers, they develop programs of study for the next three years. Beyond the Institute-wide requirements of physics, mathematics, and humanities, the Materials Science option requires one year of applied and computational mathematics and a prescribed number of units selected from a wide variety of courses in science and engineering. An undergraduate thesis is an essential part of the academic program. Any student in the Materials Science option whose grade-point average is less than 1.9 at the end of the academic year in the subjects listed in the option requirements may be refused permission to continue to work in the Materials Science option.

MS Option Requirements

1. Fulfillment of extended core requirements in Differential Equations (Ma 2 or equivalent); Probability and Statistics (Ma 3 or equivalent); Waves (Ph 2 a, Ph 12 a or equivalent), Quantum Mechanics (Ph 2 b, Ph 12 b, Ch 21 a or equivalent); Thermodynamics and Statistical Mechanics (Ph 2 c, Ph 12 c or equivalent).
2. Demonstration of competency in computer programming or computer science by taking CS 1, or by taking an approved alternative course, or by passing a placement exam administered by the computer science option.
3. 18 units of laboratory courses taken from the following list: APh 77 bc, Ae/APh 104 bc, CE 180, CS/CNS 171, CS/CNS 174, EE/CS 10ab, EE 45, EE 90, EE 91 ab, EE 110 abc, ME 50 ab, ME 72 ab, MS 121, MS/APh 122, MS 125, MS 142, or from EAS courses with the word "laboratory" in the title, but excluding those courses for which first-year laboratory credit is allowed.
4. ACM/IDS 104 and ACM 95/100 ab, or Ma 108 abc, or Ma 109 abc.
5. SEC 10 or equivalent; SEC 11, SEC 12, SEC 13 or equivalent.
6. APh 17 ab or ChE 63 ab or APh/MS/ME 105 ab.

7. MS 115 and MS/ME/MedE 116 and MS 90 (or other appropriate laboratory in MS).
8. At least 45 of additional units from the following list of restricted electives: ACM/IDS 104, Ae/AM/CE/ME 102 abc, APh/MS/ME 105 abc, APh 114 abc, APh/EE 130, APh/Ph/MS 152, APh/Ph/Ae/MS 153, APh/EE 183, Ch 21 abc, ChE/Ch/MS 113, Ch 120 ab, Ch 121 ab, Ch 125 ab, Ch/ChE 147, ChE/Ch 148, CS 11, Ge 114 ab, ME 12 abc, MS 121, MS 122, MS 125, MS 131, MS 132, MS 133, APh/MS 141, MS 142, MS/ME 161, MS/APh 162, MS/ME 166, Ph 125 abc. Substitution of courses may be approved at the discretion of the option representative.
9. Senior thesis MS 78 abc.

Passing grades must be earned in at least 486 units, including those listed in requirements 1–9 above.

MS Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
CS 1	Intro. to Computer Programming	9	-	-
Ma 2	Differential Equations	9	-	-
Ma 3	Intro. to Probability and Statistics	-	9	-
MS 90	Materials Science Laboratory	-	-	9
MS 115	Fundamentals of Materials Science	9	-	-
MS 116	Mechanical Behavior of Materials	-	9	-
Ph 2 abc or Ph 12 abc	Waves, Quantum Mechanics and Statistical Physics	9	9	9
	HSS Electives	-	9	18
	Total	**36**	**36**	**36**
Third Year				
ACM/IDS 104	Applied Linear Algebra	9	-	-
ACM 95/100 ab	Intro. Methods of Applied Math.	-	12	12
APh/MS/ME 105 abc	States of Matter	9	9	9

MS 131	Structure and Bonding in Materials	-	9	-
MS 132	Diffraction and Structure	9	-	-
MS 133	Kinetic Processes in Materials	-	-	9
	HSS Electives	9	9	9
	Lab Class	9	9	-
	Restricted Electives (from 11)	-	9	9
	Total	**45**	**48**	**48**
Fourth Year				
SEC 10	Technical Seminar Presentation	3	-	-
SEC 11, SEC 12, or SEC 13	Written Communication	-	3	-
MS 78 abc	Senior Thesis	9	9	9
	HSS Electives	9	9	9
	Lab Class	9	-	-
	Restricted Electives	18	18	18
	Total	**48**	**39**	**36**

MATHEMATICS OPTION AND MINOR (MA)

Aims and Scope

The mathematics option is designed to give students an understanding of the broad outlines of modern mathematics, to introduce current research and to prepare them for advanced work in pure mathematics or related fields. Math students go well beyond the basics to study the structures of algebra, analysis and geometry, as well as the rudiments of combinatorics and set theory. Students learn to write coherent and complete proofs of various assertions, to work out non-trivial examples and to use computational tools.

The schedule of courses in the undergraduate mathematics option is flexible. It enables students to adapt their programs to their needs and mathematical interests and gives them the opportunity to become familiar with creative mathematics early in their careers. Some students go to use their background in mathematics as an entry to other fields, such as physics, computer science, statistics, economics, business, finance, medicine and law.

First-year students considering majoring in mathematics should be aware that the department strongly recommends taking the analytical track of Ma 1 bc. Any student whose grade-point average is less than 1.9 at the end of the academic year, in the subjects under

mathematics and applied and computational mathematics may be refused permission to continue work in the mathematics options.

Ma Option Requirements

1. Ma 2.
2. Ma 3 or Ma 140 a.
3. Ph 2 bc or Ph 12 bc
4. Ma 5 abc, Ma 10, Ma 108 abc, Ma 109 abc.
5. Ma/CS 6 a or Ma 121 a.
6. Ma/CS 6 c or Ma 116 a or Ma/CS 117 a.
7. 45 additional units of Ma numbered 110 to 190 or ACM numbered 95 or above. Courses in other options with high mathematical content may be used to fulfill this requirement with the approval of the undergraduate option representative for mathematics. Of these 45 units, at most 18 can be from courses other than Caltech Ma courses.
8. Math majors must take two quarters (18 units) of a single course, chosen from the Ma course listings with numbers between 110 and 190, inclusive. In years where one of these courses is given as a one-term course only, it cannot be used to satisfy this requirement. These two quarters may include courses taken to satisfy requirements 2, 5, 6 or 7.
9. Requirements 1– 6 may not be taken pass/fail unless the course is only offered as pass/fail.
10. Passing grades must be earned in a total of 486 units, including the courses listed above.

Ma Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
Ma 2, 3	Sophomore Mathematics	9	9	-
Ph 2 bc or 12 bc	Sophomore Physics	-	9	9
Ma 5 abc	Introduction to Abstract Algebra	9	9	9
	HSS Electives	9	9	9
	Electives[1]	18	9	18
	Total	**45**	**45**	**45**
Third Year				
Ma 10	Oral Presentation	3	-	-
Ma 108 abc	Classical Analysis	9	9	9

Ma/CS 6 ac	Introduction to Discrete Mathematics	9	-	9
Ma 110-190/ACM 95+	Advanced Mathematics	9	9	9
	HSS Electives	9	9	9
	Electives[1]	9	18	9
	Total	**48**	**45**	**45**
Fourth Year				
Ma 11	Mathematical Writing	-	-	3
Ma 109 abc	Introduction to Geometry and Topology	9	9	9
Ma 110-190/ACM 95+	Advanced Mathematics	9	9	-
	HSS Electives	9	9	9
	Electives[1]	18	18	18
	Total	**45**	**45**	**39**

[1] *Includes courses completed to fulfill option requirements 5, 6 and 7.*

Mathematics Minor (Ma)

The mathematics minor is intended to supplement one of Caltech's undergraduate degrees. It is designed for students who wish to broaden their knowledge beyond their major to include mathematics. Students completing the mathematics minor requirements will have the phrase "minor in mathematics" added to their transcripts.

Ma Option Minor Requirements

1. Ma 2, or equivalent courses approved by the option representative.
2. Ma 3 or Ma 140a, or equivalent courses approved by the option representative.
3. Two three-terms Ma courses, chosen among Ma 5abc, Ma 108abc, Ma 109abc.
4. 18 additional units of selected Ma courses, approved by their minor adviser or the option representative.
5. Requirements may not be taken pass/fail unless completed during fall or winter of the first year or when the course is only offered as pass/fail.

MECHANICAL ENGINEERING OPTION (ME)

Aims and Scope

The objective of the undergraduate program in Mechanical Engineering at Caltech is to produce graduates who will attain careers and higher education that ultimately lead to leadership roles in academia, industry, and government in areas of rapidly advancing interdisciplinary technology related to fluid, solid, thermal, and mechanical systems.

The program prepares students for graduate school and professional practice and inspires them to undertake careers that provide an opportunity to address the pressing technological needs of society. Specifically, the program builds on Caltech's core curriculum to combine the individual depth of experience and competence in a particular chosen mechanical engineering specialty with a strong background in the basic and engineering sciences. It maintains a balance between classroom lectures and laboratory and design experience and emphasizes the problem-formulation and solving skills that are essential to any engineering discipline. The program also strives to develop in each student self-reliance, creativity, leadership, professional ethics, and the capacity for continuing professional and intellectual growth. For interested students, there are opportunities to conduct research with a faculty member.

The outcome of the undergraduate program is to prepare the student to build on a fundamental education in physics, mathematics, chemistry, and biology and to apply those principles to the solution of open-ended engineering problems; to design, analyze, measure, and evaluate fluid, thermal, and mechanical systems; to work effectively as part of a team; to communicate effectively; to apply ethical considerations; and to understand the broader impacts of engineering developments, including societal, cultural and environmental concerns.

Mechanical engineering is the branch of engineering that is generally concerned with understanding forces and motion, and their application to solving problems of interest to society. The field includes aspects of thermodynamics, fluid and solid mechanics, mechanisms, materials, and energy conversion and transfer, and involves the application of physics, mathematics, chemistry, and, increasingly, biology and computer science. Importantly, the field also emphasizes the process of formulation, design, optimization, manufacture, and control of new systems and devices.

Technical developments in the last decade have established the importance of interdisciplinary engineering and science, and as a result, new technical disciplines within mechanical engineering have emerged. These new areas build on an understanding of the fundamental behavior of physical systems; however, the focus of this work is on the interfaces between traditional disciplines. Examples of the new disciplines include micro- and nano-mechanical systems, simulation, and synthesis, integrated complex distributed systems, and biological engineering.

Mechanical engineers can be found in many fields, including automotive, aerospace, materials processing and development, power production, consumer products, robotics and automation, semiconductor processing, and instrumentation. Mechanical engineering can also be the starting point for careers in bioengineering, environmental and aeronautical engineering, finance, and business management.

The mechanical engineering undergraduate option is accredited by the Engineering Accreditation Commission of ABET, www.abet.org, under the General Criteria and the Mechanical Engineering Program Criteria.

At the end of the first year, students who elect the Mechanical Engineering Option are assigned advisers as close to their expressed field of interest as possible, and together they develop programs of study for the next three years.

A student whose interests relate to mechanical engineering, but who wishes to pursue a broader course of study than that allowed by the requirements below, may elect the Engineering and Applied Science Option.

Attention is called to the fact that any student whose grade-point average is less than 1.9 at the end of the academic year in the required courses listed below may be refused permission to continue work in this option.

ME Option Requirements

1. Technical communication: SEC 10 and one of SEC 11, SEC 12, or SEC 13.
2. Mathematics: Ma 2, ACM 95 ab, and 9 units selected from Ma 3, Ma/CS 6 a, ACM/IDS 104, or other ACM courses numbered 100 and above.
3. Physics: 18 units selected from Ph 2 abc.
4. Computing: 9 units selected from ACM 11, CS 1, CS 2, CS 11.
5. ME Core: ME 10, ME 11 abc, ME 12 abc, ME 13, ME 14, ME 40, and ME 50 ab.
6. Capstone design: ME 72 ab or ME 90 abc or CS/EE/ME 75 abc.*
7. 45 units of advanced engineering electives selected from a list of approved courses or from courses pre-approved by the Option Representative. 27 units must be from one track (depth requirement) and at least 9 units from two other tracks (breadth requirement).**
8. Courses satisfying requirements 1 through 7 must be taken for grades, unless they are only offered pass/fail.

* Students electing CS/EE/ME 75abc or ME90 must complete at least 27 units distributed amongst all three quarters and must be able to demonstrate that their contribution to the overall project builds on their knowledge and skills acquired in earlier coursework such as ME11, ME12, ME13, and ME14 and incorporates appropriate engineering design standards and multiple design constraints.

** These courses are selected in consultation with the student's adviser and are typically taken in the third and fourth years. Please

consult the Mechanical and Civil Engineering website and/or the adviser for further information.

ME Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
Ma 2	Differential Equations	9	-	-
ME 10	Thinking Like an Engineer	1	-	-
ME 11 abc	Thermal Science	9	9	9
ME 12 abc	Mechanics	9	9	9
ME 13	Mechanical Prototyping	4	-	-
ME 14	Design and Fabrication	-	-	9
ACM 95 ab	Intro. Meth. Applied Math.	-	12	12
	HSS Electives	9	9	-
	Total	**41**	**39**	**39**
Third Year				
	Physics Electives	9	-	9
ME 50 ab	Exp. and Modeling in ME	-	12	12
ME 40	Dimensional and data analysis in engineering	9	-	-
	Capstone Design	12	15	-
SEC 10	Technical Seminar Presentations	3	-	-
one of SEC 11-13	Written Communication	-	-	3
	HSS Electives	9	9	18
	Total	**42**	**36**	**42**
Fourth Year				
	Math Electives	9	-	-
	Advanced ME Electives	18	18	9
	HSS Electives	9	9	9
	Total	**36**	**27**	**18**

NEUROBIOLOGY MINOR (NB)

Aims and Scope

The Neurobiology minor is intended for those who wish to supplement their Caltech undergraduate degree with knowledge of neurobiology. The student's transcript will include the phrase "minor in Neurobiology". A Neurobiology minor is not available to majors in the CNS or Biology options.

NB Minor Requirements

1. Biology fundamentals. Bi 8 and Bi 9
2. Intermediate biology: Genetics: Bi 122; Development: Bi 117 or Bi/BE 119; plus nine units of other 100-level Bi, NB, or Ch courses
3. Introduction to neuroscience: NB/Bi/CNS 150
4. Advanced neurobiology: 18 additional units of 100- or 200- level NB electives, that are not applied to the above requirements and are not simultaneously used for fulfilling a requirement of the student's major option, approved by their assigned biology advisor or the option representative.

PHILOSOPHY OPTION AND MINOR (PL)

Aims and Scope

The philosophy option provides students with a broad education in philosophy that is designed to complement the scientific curriculum at Caltech. Philosophy majors will be expected to learn about some of the major figures and movements in the history of philosophy, and to learn about contemporary philosophical debates. The philosophy option also aims to provide students with new perspectives on the material they learn in their science courses, and to enable them to bring their technical skills and scientific learning to traditional problems in philosophy.

The philosophy curriculum will help students to acquire the basic tools of philosophical analysis: the ability to read and interpret philosophical texts; the ability to identify strengths and weaknesses of philosophical arguments; the ability to develop well-reasoned defenses of philosophical positions; and the ability to anticipate objections to one's own views. In addition, the philosophy option will train students to express themselves clearly and concisely in both writing and speaking. These critical thinking and communication skills provide an excellent foundation for any intellectual endeavor, and are critical to those pursuing careers in fields such as law, business, medicine, and scientific research.

The courses in the philosophy option concentrate in four major areas: philosophy of science; philosophy of mind, brain, and behavior; history of philosophy; and ethics. In their coursework, students will have the opportunity to discuss and debate philosophical issues in small groups, and will learn how to offer and receive constructive criticism. They will also receive detailed feedback on their persuasive writing from several different members of the philosophy faculty.

In their senior thesis, philosophy majors will have the opportunity to pursue more intensive research in one particular area of philosophy, and to sustain an argument on a larger scale, while working one-on-one with a member of the philosophy faculty. This will provide interested students with a solid foundation for graduate work in philosophy and related fields.

Philosophy majors must take at least 99 units of philosophy courses during their four years as undergraduates. These must include 18 units of Pl 90 ab, to be taken in any two consecutive terms in the senior year. The 99 units may include nine units of first-year humanities in philosophy (courses cross-listed Hum/Pl numbered 60 or below), nine units of Pl 98, and up to 18 units of study in related disciplines.

Depending on their interests, philosophy majors may be required by the option representative or their advisers to take up to 18 units in one or more related areas. For example, students writing on political philosophy or philosophy of neuroscience will be expected to have the appropriate political science or neuroscience background. Students whose primary interest lies in the philosophy of science—particularly in the philosophy of specific sciences such as physics or biology—will have their intellectual interests best served by taking classes in both the history and philosophy of science. Such students are encouraged to pursue the HPS option; or, if they choose the philosophy option, they may be required to take some history of science courses as part of their 99-unit requirement.

Students considering the philosophy option will be well advised to take a first-year humanities course in philosophy. From the sophomore year onward, they should plan on taking one philosophy course per term, culminating in two terms of Pl 90 ab in the senior year. Students in Pl 90 ab work with a faculty adviser to write a 10,000- to 12,000-word paper on a topic of mutual interest. Senior theses are expected to be of a high standard and to form the basis of students' applications to graduate study in philosophy, should they so desire. With the exception of Pl 98 and courses taken during the first two quarters of the first-year student's first year, all courses to be counted toward the philosophy option must be taken for grades unless special permission is granted by the option representative.

Pl Option Requirements

1. Pl 90 ab.
2. 63 units of advanced philosophy courses, numbered 99 or above. Up to nine units of first-year humanities in philosophy (courses cross-listed Hum/Pl numbered 60 or below) and/or up to nine units of Pl 98 may be substituted for up to 18 of these advanced units.
3. 18 units of advanced philosophy courses numbered 99 or above, or advanced non-philosophy courses that are closely related to the student's area(s) of philosophical interest. (Students wishing to count non-philosophy courses toward their option requirements must obtain prior approval from the philosophy option representative or their adviser. Students will normally not

be permitted to satisfy this requirement with core courses.)
4. 54 units of science, mathematics, and engineering courses in addition to the core. This requirement cannot be satisfied by core or menu courses, or by courses listed as satisfying the introductory laboratory requirement. Students are strongly encouraged to choose their additional courses in areas that complement their philosophy studies.
5. Three units of oral communication. En 84 satisfies this requirement, as do oral communication courses offered by other options.
6. Passing grades must be earned in a total of 486 units, including the courses listed above.

Courses used to complete the philosophy option under categories 1, 2, or 3 above may not be used to satisfy the requirements of another option or minor.

Pl Minor Requirements

The minor in philosophy is designed for students who want to pursue concentrated study in philosophy without the extensive course work and the senior thesis required by the philosophy option.

Philosophy minors must complete 72 units of philosophy courses. Students wishing to do a minor in philosophy must declare a minor with the philosophy option representative. Students completing the philosophy minor requirements will have the phrase ”minor in philosophy” added to their transcripts. With the exception of Pl 98 and courses taken during the first two semesters of a first-year student’s first year, all courses to be counted toward the philosophy option or minor must be taken for grades unless special permission is granted by the option representative.

1. 72 units of philosophy courses numbered 99 or above.
2. Nine units of Pl 98 may be substituted for any nine units of the 72 required for the minor.
3. Nine units of first-year humanities in philosophy (courses cross-listed Hum/Pl numbered 60 or below) may be substituted for any nine units of the 72 required for the minor.

Courses used to complete the philosophy minor may not be used to satisfy the requirements of another option or minor.

PHYSICS OPTION (PH)

Aims and Scope

The physics option offers instruction in the fundamentals of modern physics and provides a foundation for graduate study, which is generally necessary for a career in basic research. The physics program also forms an excellent basis for future work in a variety of applied fields.

An intensive version of the sophomore physics course (waves, quantum mechanics, and statistical mechanics) is offered for those

planning further study in physics, and the required junior-level courses give a thorough treatment of fundamental principles. Elective courses taken during the junior and senior years allow students to explore their particular interest. Some electives offer broad surveys, while others concentrate on particular fields of current research. A selection of laboratory courses is offered at several levels. Students interested in concentrating their studies in one specific area of physics should refer to the undergraduate physics website for course schedule recommendations.

Students are encouraged to become active participants in research on campus, both during the summer and during the school year. Academic credit for physics work done outside of the classroom can be awarded in a variety of ways.

Students must maintain a grade-point average of 1.9 or better each year in the subjects listed under this division to remain in the physics option.

Ph Option Requirements

The first five requirements should be completed by the end of the second year. In planning a program, note that Ph 6 and Ph 7 are each offered only once per year, in the second and third terms, respectively. The pass/fail option cannot be exercised for any courses used for these requirements with the exception of courses that do not offer grades.

1. Ph 3. [1]
2. Ma 2 and Ma 3. [2]
3. Ph 12 abc.
4. Ph 6.
5. Ph 7 or APh/EE 24. [3]
6. 18 units of Ph 77, or 27 units of Ph 78 (experimental thesis project), or 9 units of Ph 77 and 9 units from APh 77 or Ay 105, or 9 units of Ph 77 and 9 units of Ph 177.
7. Ph 70. [4]
8. Ph 106 abc.
9. Ph 125 ab.
10. Ph 21 or Ph 22 or one term of Ph 121 abc, Ay 190, APh/MS 141 or CS 155.

[1] Other laboratory courses may be substituted for the Ph 3 requirement, including Ph 5, Ph 8 bc, or APh 9 a.

[2] Other statistics courses, e.g., Ge/Ay 117 or ACM 112, may be substituted for Ma 3.

[3] APh 23 is a prerequisite for APh/EE 24 and can be used towards the advanced physics elective requirement.

[4] Other communication courses e.g., Ay 30 (or Ay 141) and 31 or Ma 10 and 11 may be substituted for Ph 70.

Ph Required Electives

1. 90 units of Advanced Physics Electives, in addition to the above, include any of the following: any Ph, APh, or Ay, course numbered 100 or above, or any of Ph 5, Ph 22, Ph 78, Ph 79, ACM 95, ACM 101, APh/EE 23, Ma 5, Ma 108, or up to 10 units for Ay 20 – 21. Nine units towards the 90 unit requirement will be given for taking three terms of Ph 77. Students are encouraged to take ACM 95 or the quarter of Ph 129 that covers analysis as part of this requirement. If a letter grade option is available, the pass/fail option cannot be exercised for any courses used for this requirement with the exception of ACM 95 and up to 36 units of Ph courses numbered 200 or above. No more than 27 units of Ph 171-172/APh 100/Ay 142 may apply toward this requirement without permission from the Undergraduate Option Representative. Additionally, Ph 171-172/APh 100/Ay 142 may only apply toward this requirement if taken in increments of six units or more and a written summary (2-4 pages in length) of the work completed is submitted to the Undergraduate Option Representative within 2 weeks of the beginning of the subsequent quarter. Students may also petition the Undergraduate Option Representative to request that courses from other options with suitable physics content apply toward this requirement.
2. Nine units of science and engineering electives outside of Ph, Ay, APh, Ma, and ACM. These units are in addition to the required Core science electives.

Passing grades must be earned in a total of 486 units, including the courses listed above.

Ph Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
Ph 12 abc	Waves, Quantum Physics, and Statistical Mechanics	9	9	9
Ma 2, Ma 3	Sophomore Mathematics	9	9	-
Ph 6, Ph 7	Physics Laboratory	-	9	9
ACM 95 ab	Intro. Methods of Applied Math	-	12	12
Ph 21/22	Computational Physics	-	-	6
	HSS and/or PE Electives	18	9	9
	Science/Engineering Electives	9	-	-
	Total	**45**	**48**	**45**

Third Year				
Ph 106 abc	Topics in Classical Physics	9	9	9
Ph 121 abc	Advanced Computational Physics	6	-	-
Ph 125 ab	Quantum Mechanics	9	9	-
Ph 70	Oral & Written Communication	6	-	-
	HSS and/or PE Electives	9	9	9
	Advanced Physics Electives	9	18	30
	Total	**48**	**45**	**48**
Fourth Year				
Ph 77 abc	Advanced Physics Laboratory	9	9	-
	Advanced Physics Electives	18	9	18
	Electives	9	18	18
	HSS and/or PE Electives	9	9	9
	Total	**45**	**45**	**45**

POLITICAL SCIENCE OPTION (PS)

Aims and Scope

The political science option provides students with training in the substance and methods of modern political science, including the analysis of representative democracy, electoral institutions, the allocation of public goods, and regulatory behavior. The option emphasizes formal tools like game theory, social choice theory, and formal political theory along with quantitative methodologies to test those theories. In addition, the option encourages original research. The design of the political science option ensures that students will be well suited to pursue careers in government or the private sector, as well as to pursue graduate work in political science, law, or public policy. Students who complete the political science option can expect the following learning outcomes:

- an understanding of and ability to use the theoretical tools of social choice and game theory as applied to politics;
- an understanding and knowledge of how to apply quantitative methods to study politics;
- the ability to present complex theoretical and quantitative material in research reports and presentations; and
- the skills necessary to pursue graduate education and careers in law, government, politics, or public policy.

Note: The official source on requirements for graduation is the Caltech catalog from the year in which a student began studies at Caltech. Please see the catalog online, from this and previous years, for information regarding the applicable option requirements.

PS Option Requirements

1. PS 12, PS 132, Ec 122.
2. Four political science courses from the list: PS 120, 123, 125, 135, PS 139, PS 141ab, PS/Ec 172, or any other 100-level PS courses with the approval of the Political Science Option Representative.
3. Ma 3.
4. 36 additional units in advanced political science, economics, law, social science, psychology, or history.
5. 36 additional units in advanced social science, science, engineering, or mathematics.
6. Passing grades must be earned in a total of 486 units, including all courses used to satisfy the above requirements.
7. Writing/oral presentation courses: a scientific writing requirement course, and a three-unit course in oral communication, offered by any division (some options combine these two requirements into one course, that can be taken to satisfy this requirement), or En/Wr 84. The course used to satisfy this requirement must be taken on grades.

PS Typical Course Schedule

		Units per term		
		1st	*2nd*	*3rd*
Second Year				
Ma 3	Probability & Statistics	-	9	-
PS 12	Introduction to Political Science	9	-	-
PS 132	Formal Theories in Political Science	9	-	-
Ec 122	Econometrics	9	-	-
	Electives	18	36	45
	Total	**45**	**45**	**45**
Third Year				
	Political Science Electives [1]	18	18	18
	Electives	27	27	27
	Total	**45**	**45**	**45**
Fourth Year				

	Political Science Electives [1]	18	18	18
	Electives	27	18	18
	Total	**45**	**36**	**36**

[1] See option requirements 2, 5, and 6.

ROBOTICS MINOR (RO)

Aims and Scope

The robotics minor is intended to supplement one of Caltech's undergraduate degrees and is designed for students who wish to broaden their knowledge beyond their normal major, including those who wish to pursue a career or graduate education in robotics. Students completing the robotics minor requirements will have the phrase "minor in robotics" added to their transcripts. The minor is a collaboration between the CMS, MCE, and EE departments in EAS.

Robotics, most generally, is an interdisciplinary field with the goal of creating capable and intelligent machines. It naturally integrates aspects of mechanical and electrical engineering with computer science while connecting with many other disciplines. Following the "sense-think-act" paradigm, robots have to (i) use a variety of sensors to continually observe and make sense of the real world in real time, (ii) use appropriate algorithms to consider decisions, make plans, and reason about how to influence the world, considering their own abilities, and (iii) leverage their physical embodiment to move in and take action on the world.

The robotics minor embraces multiple disciplines to draw strong connections between theory, computation and the physical world, both in the course requirements as well as the course materials. The core robotics classes teach fundamental concepts and challenge students to develop strong intuition via hardware projects. The minor provides students not just the ability to pursue robotics directly but also a perspective on how their major impacts other fields and how to work across disciplines throughout their careers.

Robotics Minor Requirements

1. Computer Science Fundamentals. CS2.
2. Mathematics Fundamentals. Ma 2; (Ma 3 or Ma/ACM/IDS 140a or ME 40 or EE 55).
3. Engineering Fundamentals. ME/CS/EE 129; ME 13 or EE/ME 7.
4. Robotics Core. ME/CS/EE 133ab; (ME/CS/EE 134 or ME/CS/EE 169)
5. Advanced Robotics and Controls. Two courses from among the following: ME/CDS/EE 234ab; ME/CDS 235ab; CDS 110; CDS 131; CDS 212; CDS 232.
6. Intelligence. One course from among the following: CMS/CS/CNS/EE/IDS 155, EE/CNS/CS 148, or CNS/Bi/EE/CS/NB 186.

With the approval of the option representative, up to 9 research units may be applied to satisfy requirements 5 or 6, e.g., via CS 80, CS 81, EE 80, EE 99, ME 90, or ME 100, culminating in a required report reviewed by the research adviser.

Courses used to fulfill requirements 1, 2, and 3 (fundamentals) may be used to fulfill another major or minor or the Institute's humanities and social sciences requirements.

Courses used to fulfill requirements in 4, 5 & 6 can not be used to fulfill (i) a requirement for another major or minor or (ii) the institute's humanities and social sciences requirements. Any replacement of these courses must be discussed with the option administrator.

Pass/fail grading cannot be elected for courses taken to satisfy minor requirements. Courses taken as part of the minor are counted toward the total 486 units needed for Institute graduation requirements.

STRUCTURAL MECHANICS MINOR (SM)

Aims and Scope

This minor is intended to supplement one of Caltech's undergraduate degrees and is designed for students who wish to broaden their knowledge beyond their normal major, especially for those who wish to join the structural engineering profession after graduation or pursue a graduate degree in structural mechanics or structural engineering. Students completing the structural mechanics minor requirements will have the phrase "minor in structural mechanics" added to their academic transcripts.

SM Minor Requirements

The student must complete 54 units of classes selected from Ae/AM/CE 102 abc, AM/CE 151, Ae/CE 221, Ae/CE 165ab and CE 160 ab, and obtain a grade of B– or higher. Courses taken as part of the structural mechanics minor are counted toward the total 486-unit Institute graduation requirement.

VISUAL CULTURE MINOR (VC)

Aims and Scope

The minor in Visual Culture provides students with an intensive education in visual histories and theories. Visual Culture minor students will become familiar with a range of visual forms, from the traditional fine arts to film and digital media, as well as with histories and theories of vision and visuality. Students will also learn essential skills of visual and media literacy through both close formal analysis of objects and contextualized readings that emphasize differences across history and geography. Visual Culture courses emphasize writing and critical reading of both written texts and images, including through practice-based courses taught by artists in residence, in order to help students to develop communication skills that can enhance their careers as scientists, engineers, and medical professionals. The

Visual Culture minor also provides excellent preparation for those seeking careers in any field that involves extensive written, oral, and/or visual communication.

Visual Culture Minor Requirements
Visual Culture minors must take 72 units of Visual Culture courses. These units may include one first-year humanities course; they may also include one directed reading course (VC 90). Students wishing to do a minor in Visual Culture must declare a minor with the Visual Culture option representative. All courses to be counted toward the minor in Visual Culture must be taken for grades with the exception of: a) one directed reading course, and b) a first-year humanities course in Visual Culture when taken in the first two quarters of a first-year student's first year. Students completing the Visual Culture minor requirements will have the phrase "minor in Visual Culture" added to their transcripts.

1. 72 units of Visual Culture courses numbered 99 or above.
2. Nine units of first-year humanities in Visual Culture (courses cross-listed Hum/VC numbered 60 or below) may be substituted for any nine of the 72 units required for the minor.
3. Nine units of VC 90 [directed reading] may be substituted for any nine of the 72 units required for the minor.
4. Nine units of Visual Culture courses numbered between 61 and 89 may be substituted for any nine of the 72 units required for the minor.

Courses used to complete the Visual Culture minor may not be used to satisfy the requirements of another option or minor. However, these courses may be used to satisfy core Institute requirements in the humanities.

Section Four

Information for Graduate Students

The Institute offers graduate degrees of Master of Science and Doctor of Philosophy, and in special cases the degree of Engineer.

The Institute is organized into six academic divisions: Biology and Biological Engineering; Chemistry and Chemical Engineering; Engineering and Applied Science; Geological and Planetary Sciences; the Humanities and Social Sciences; and Physics, Mathematics and Astronomy.

Graduate work at the Institute is further organized into graduate options, which are supervised by those professors whose interests and research are closely related to the area of the option, within the administrative jurisdiction of one or more of the divisions.

A faculty member serves as the representative for an option. The option representative provides consultation on academic programs, degree requirements, financial aid, etc., and provides general supervision to graduate students in the option. The Graduate Studies Committee, which includes the graduate option representatives and the dean of graduate studies, exercises supervision over the scholastic requirements established by the faculty for all advanced degrees, provides policy guidance to the dean of graduate studies, and certifies all candidates for graduate degrees to the faculty for their approval. A list of the option representatives for the current academic year can be found at registrar.caltech.edu/current-students/option-reps.

GRADUATE POLICIES AND PROCEDURES

ADMISSION TO GRADUATE STANDING

Application

An application for admission should be completed online through the Graduate Studies Office at gradoffice.caltech.edu/admissions. Admission is granted once a year to a limited number of students who show promise for scholarship and research at the highest level. Completed applications are due between November 15 and December 15, for enrollment at the beginning of the fall term of the following year. Applicants will automatically be considered for financial aid; no additional application is required.

To be admitted to graduate standing, an applicant must have received a bachelor's degree, or the equivalent, representing the completion of an undergraduate course in science or engineering related to one of the options offered by the Institute. Applicants must, moreover, have attained a scholastic record and provide recommendations to indicate the ability to pursue, with distinction, advanced study and research. The graduate program thrives on individuals from a diverse range of backgrounds and experiences, and we highly encourage applications from members of groups underrepresented in science and engineering. Graduate admission is covered by Caltech's Nondiscrimination Policy.

Applicants should refer to the Graduate Studies Office website for additional requirements, a list of supporting documents, and option-specific application deadlines.

Please note that students admitted to Caltech's PhD program will be provided with financial support for tuition and living expenses to enable them to maintain the singular focus and high level of productivity expected of students in the program. Most of the funding sources for this support require that the student be authorized to work in the United States. Consequently, matriculation into the PhD program requires evidence of work authorization, unless alternative financial support can be arranged with the admitting option.

International Students

In order to be admitted for graduate study, students from non-English-speaking countries are expected to read, write, and speak English and comprehend the spoken language. Although not required for admission, applicants whose native language is not English or have not received a degree from a university or college where English is the primary language of instruction, should be able to demonstrate a strong capability in English prior to admission to Caltech. This can be done by self-reporting scores from the Educational Testing Service (TOEFL), Pearson Test of English Academic (PTE Academic), the Cambridge Examinations and the International English Language Testing System (IELTS), or other services that provide a certified English-language proficiency examination.

All international students are evaluated upon arrival at Caltech and, if it is determined that additional instruction in English is needed, they will be assigned to an English as a Second Language (ESL) course. To be a candidate for an advanced degree, the student must have clear self-expression in both oral and written English.

VISITING STUDENT APPOINTMENTS

A limited number of visiting student appointments are made each year. Visiting student status is restricted to students who hold a bachelor's degree and are current graduate students at another institution. The invitation process requires sponsorship by a Caltech faculty member, and requests should be made directly to the Graduate Studies Office, following the visiting student instructions on the Graduate Studies Office website. The Dean of Graduate Studies may limit the number of visiting students in any given year. Visiting students are subject to the Honor System and to all Institute policies, including the Institute Sex- and Gender-Based Misconduct Policy. Violations of policy may affect a student's eligibility to continue enrollment.

Visiting graduate students are categorized into two main classifications: Special Students and Visiting Student Researchers.

Special Students

Special Students are a classification of visiting students who are currently on leave from another graduate degree program and are invited by a Caltech faculty host to conduct research for a limited duration. These students are eligible to receive academic transfer credit to be reflected on a Caltech transcript and may receive a stipend. Full-time enrollment, in a graduate research course and/or coursework numbered 100 or higher, is required and credits may be transferred to the home institution. Special Students, however, will not be considered to be working toward a Caltech degree, and courses taken under this program cannot be used to fulfill the requirements for a Caltech degree, nor does registration count toward the minimum residency requirement for an advanced degree. Special Student appointments are granted for a minimum of one term to one year, renewable each year up to a maximum of three years. Special Students are required to provide proof of vaccinations in accordance with Institute policies, and any other required medical and immunization records for the duration of the visit.

Special Students are eligible for Caltech benefits and other student privileges as defined by their enrollment status. Special Students who receive a full Caltech stipend will also receive tuition and fees coverage, paid by the faculty host. Special Students who do not receive a Caltech stipend will be responsible for paying a reduced tuition and fees rate. (For current rates, see the Expense Summary.)

Visiting Student Researchers

Visiting Student Researchers (VSR's) are a classification of visiting students who are not eligible to receive academic credit from Caltech but will receive a Caltech identification card. VSR's are limited to short-term visits of one month to one year and the status is not renewable. Participants are required to provide proof of health insurance, vaccinations in accordance with Institute policies, and any other required medical and immunization records for the duration of the visit.

VSR's are not eligible to receive a stipend through the Institute payroll and are not otherwise eligible for Caltech privileges that are normally extended to enrolled students. Reimbursements for research-related expenses is possible, but it is the Caltech faculty host's responsibility to ensure that the supporting grant can be used for such purposes and that there are no restrictions. Visiting students who wish to receive a stipend through the Institute payroll and/or require academic credit reflected on a Caltech transcript must instead be appointed as a Special Student.

Exchange Programs

Some academic options have formal exchange programs that they have arranged with other institutions. Exchange students must have a visiting student appointment, and the type of appointment will depend upon the terms of the agreement for the particular exchange program. These programs are administered by the option, and requests should be made directly to the Graduate Studies Office following the same

procedure for visiting students.

GRADUATE RESIDENCE

One term of residence shall consist of one term's work of not fewer than 36 units of advanced work in which a passing grade is recorded. Advanced work is defined as study or research in courses whose designated course number is 100 or above. If fewer than 36 units are successfully carried, the residence will be regarded as short by the same ratio, but the completion of a greater number of units in any one term will not be regarded as increasing the residence. In general, the residency requirements are as follows: for Master of Science, a minimum of three terms of enrollment; for the degree of Engineer, a minimum of eight terms of enrollment; and for Doctor of Philosophy, a minimum of 12 terms of enrollment.

REGISTRATION

Graduate students are required to register for each term, including summer, whether they are taking classes, conducting research, doing independent reading, writing a thesis, or utilizing any other academic service or campus facility.

A graduate student must be registered for a minimum of 36 research and/or course units to be classified as a full-time student, and may not enroll in excess of 36 research units. A graduate student who registers for less than 36 total units, or who undertakes activities related to the Institute aggregating more than 62 hours per week (in class, research, and teaching assistantship units), must receive approval in advance from the Dean of Graduate Studies. A petition for this purpose may be obtained from the Graduate Studies Office website and must carry the recommendation of the option representative of the student's major option before submission.

Graduate students register during a two-week period each quarter. A late registration fee of $50 is assessed for failure to register on time. Graduate students with a Bursar's bill balance of $1,500 or more may have a hold placed on their registration for the subsequent term the day before online registration opens. The hold will be released once students have paid their bill or worked out a satisfactory payment plan with the Bursar's Office.

Before registering, students should consult with their adviser. An adviser is assigned to each entering graduate student by the option representative. In most options, a new adviser is assigned when the student begins research. Only members of the professorial faculty may serve as advisers. With the approval of the Dean of Graduate Studies, any graduate student whose work is not satisfactory may be refused registration at the beginning of any term by the division in which the student is doing their major work. See the section on Satisfactory Academic Progress for more information.

In registering for research, students should indicate the name of the instructor in charge and should consult with the instructor to determine the number of units to which the proposed work corresponds. At the end of the term, the instructor in charge may decrease the number of units for which credit is given if the instructor

feels that the progress of the research does not justify the original amount.

Students will not receive credit for courses unless they are properly registered. Students themselves are responsible for making certain that all grades to which they are entitled have been properly recorded. Please note that graduate students who enroll in courses numbered below 100 will not receive credit for those courses unless the course(s) is specified in the requirements for a graduate degree as stipulated in the *Caltech Catalog*.

All changes in registration must be reported to the Registrar's Office by the student. Such changes are governed by the last dates for adding or dropping courses as shown on the Academic Calendar. A student may not withdraw from or add a course after the last date for dropping or adding courses without the option's consent, written approval from the instructor of the relevant course, and the approval of the Dean of Graduate Studies.

If the withdrawal occurs after Add Day of any term, a W (standing for "withdrawn") will be recorded on the student's transcript for all courses in which the student is enrolled. A grade of W is not included in the computation of the student's grade-point average.

General Administrative Requirements

Graduate students are required to have continuity in registration, maintain full-time status, make satisfactory progress, and be academically enrolled until all requirements for a degree are fulfilled. This means that students must either be registered, enrolled or on an approved leave from the Institute. Students who fail to do so can be withdrawn from the Institute. Reduced duty status maintains registration for a student who cannot carry a full load due to a medical condition, disability or pregnancy.

Registration is required for the term in which the thesis defense is undertaken, with the exception of the first week of each term. Approval of the Dean is required for any student seeking to enroll for a subsequent term beyond the defense during the academic year. Once the degree is conferred, further enrollment as a graduate student is not permitted.

Detached duty status maintains registration for a student doing research at an external location, such as a national laboratory or another academic institution, for an extended period.

Students are entitled to at least two weeks' annual vacation (in addition to Institute holidays), and they should arrange their vacation schedules with their research advisers early in each academic year. Any questions should be referred to the Graduate Studies Office.

If a student fails to register by Add Day, they will be placed in "Separated/Inactive" status and will be ineligible to be receive a stipend or use Institute facilities. Key cards will be inactivated and a hold may be placed on their paycheck.

To avoid being placed in "Separated/Inactive" status, the student must petition the Dean through the Graduate Studies Office and resolve their status prior to being reinstated or placed on an approved leave.

GRADUATE STUDENT LEAVES OF ABSENCE

Graduate students must be continuously enrolled in a full-time status, making satisfactory academic progress, and in residence at the Institute during their graduate studies unless they request and receive permission from the Dean of Graduate Studies by submitting a petition for one of the available leave categories or Detached Duty. This includes the summer term.

If a student fails to register for a full-time load of classes (36 units) by Add Day, they will be placed in "Separated/Inactive" status and will be ineligible to be receive a stipend or use Institute facilities. Key cards will be inactivated and a hold may be placed on their paycheck.

To avoid being placed in "Separated/Inactive" status, the student must petition the Dean through the Graduate Studies Office and resolve their status prior to being reinstated or placed on an approved leave.

Leave of Absence from Graduate Studies

If a graduate student needs to take a leave (sabbatical) from the Institute, they must petition through the Graduate Studies Office.

Leaves are granted for a fixed duration from one term up to a maximum of one year. Leaves may be extended only with the agreement of the Advisor, Option Representative, and the permission of the Dean of Graduate Studies.

Prior to going on leave, students must discuss with their Option and Caltech faculty advisor the conditions of return. Return from leave is conditional upon the Option's and advisor's willingness to accept the student for continuing study, and the availability of funding. When returning from leave, students must provide at least six (6) weeks of notice to the Graduate Studies Office and contact the Assistant or Associate Graduate Dean to determine whether a meeting is required to discuss resuming a full-time program.

A graduate student who does not return from leave as planned or does not file an extension request will be withdrawn from the Institute.

While on Leave

Caltech considers students on an approved leave to be matriculated; however, students on leave are not currently enrolled and therefore do not enjoy all rights and privileges of enrolled students. Separated students (i.e. unenrolled students), and accordingly, students on leave, have limited access to Caltech's educational activities, programs, and services. Students on leave do not have access to online services including but not limited to REGIS and Canvas. They may not attend classes or labs, live in Institute housing*, or access certain student resources, including Student Wellness Services, CASS, and Residential Life activities, programs, and services during their leave. Career Advising and Experiential Learning (CAEL) is, by default, open to all students who have not been permanently separated from the Institute, regardless of leave or enrollment status, unless otherwise revoked by the Director of CAEL or the dean. For questions regarding the full scope of these limitations, please contact the Graduate Studies Office. [*Students on an

approved pregnancy leave or bonding leave are eligible to retain Caltech housing privileges.]

Students may consult with their advisor and otherwise plan for their academic future; however, they will not receive credit for courses unless they are properly enrolled. Students who are on leave are still subject to all Institute policies, including the Institute Sex- and Gender-Based Misconduct Policy. Violations of policy may affect a student's eligibility to re-enroll.

Personal Leave

Students who wish to take a personal (non-medical) leave must petition through the Graduate Studies Office. While on a personal leave, students are not eligible for subsidized Caltech healthcare benefits, stipends, or other student benefits. Please refer to the conditions for students on Personal Leave from the Institute. Return from leave is subject to the support of a Caltech professorial faculty advisor and availability of funding.

A student may request a voluntary leave of absence for personal reasons by submitting a personal (non- medical) leave petition to the Graduate Office for approval. International students should consult with the International Student Programs (ISP) office regarding visa implications prior to submitting the leave petition.

The dean may grant a personal leave provided (a) the student is making satisfactory academic progress as determined by the student's adviser, (b) the leave is for one year or less, although special circumstances can be considered for a longer leave, and (c) the leave extends over a period that includes at least one full term.

A petition to return from a personal leave should be submitted six (6) weeks before the first day of the term for which the student intends to return. Return from a personal leave is subject to the approval of the dean and is subject to the student having an approved adviser and ongoing funding to support the student's research. If a student does not anticipate having an adviser upon return, they will need to work with the option representative to arrange for funding and a new adviser in advance of the return. Return will only be granted once an adviser and funding are in place.

Medical Leave

If a student is unable to complete their coursework or other course of study due to medical reasons, the student may petition for a medical leave of absence by submitting a medical leave petition, endorsed by the director of Student Wellness Services or their designee, to the Graduate Office for approval. International students should consult with the International Student Programs office regarding visa implications prior to submitting the medical leave petition.

Medical leaves are expected to extend over a period that includes at least one full term, although special circumstances may be considered for approval of a shorter leave upon the recommendation of a student's treatment team.

Students may be required to sign a release of information form authorizing their treatment provider to communicate relevant medical

information to representatives within Health and Counseling Services and the Dean's Office to facilitate evaluation of the need for the leave and to determine appropriate conditions associated with the leave and establishing expectations for return from the leave.

The Institute may impose conditions on return from a medical leave, which may include confirmation from the student's health care provider that the student is following the recommended course of treatment, the student's consent for the provider to discuss the student's condition or progress during the leave with Caltech officials, including representatives of Health and Counseling Services and the Dean's Office, and an independent evaluation of the student's readiness to return by a qualified medical professional. Certain conditions of return will be specified at the time of the leave approval.

While on Leave

It is the expectation that a student on medical leave will focus on receiving treatment to manage the condition(s) that precipitated the leave.

Students who have the Caltech-sponsored student health insurance plan will have the opportunity to continue purchasing this insurance while on medical leave.

Students on medical leave will not be able to access Student Wellness Services during their leave; however, they will be able to use the free TimelyCare service (timelycare.com/Caltech) during their leave as long as they have an active access.caltech account.

A student returning from a leave for medical reasons will maintain the same academic standing that they had previously – i.e., if on academic probation, the student will remain on probation upon return from leave.

The duration of a medical leave should be determined primarily by the student's improvement in treatment. In general, however, medical leaves are expected to include at least one full term.

Returning from Leave

The Institute may impose conditions on return from a medical leave, which may include confirmation from the student's health care provider that the student is following the recommended course of treatment, the student's consent for the provider to discuss the student's condition or progress during the leave with Caltech officials, including representatives of Student Wellness Services and the Graduate Office, and an independent evaluation of the student's readiness to return by a qualified medical professional. Any conditions of return will be specified at the time of the leave approval.

A petition to return from medical leave must be submitted six (6) weeks before the anticipated term for which the student intends to return. The return process includes an interview with the director of Student Wellness Services or their designee and the submission of a completed return from medical leave petition and provider recommendation. Students are expected to sign a release of information form authorizing their treatment providers to communicate with Caltech, including representatives of Student Wellness Services

and the Graduate Office to determine readiness to return and any recommendations for reasonable accommodations. Return from a medical leave of absence is subject to the final approval of the dean. If the student is permitted to return from the leave, any conditions of return will be communicated to the student in writing.

It is the expectation that a student on medical leave will focus on receiving treatment to manage the condition(s) that precipitated the leave.

A student returning from a leave for medical reasons will maintain the same academic standing that they had prior to the leave and will be subject to the same academic requirements for maintaining academic progress. Additional information and resources regarding medical leave, including financial and transcript implications, can be found at gradoffice.caltech.edu/admissions/policies/LeavePolicy.

Pregnancy and Bonding Leave

Pregnancy

Students who are unable to complete their coursework or other course of study for a period of time due to a pregnancy, childbirth and related medical conditions are eligible for a pregnancy leave of absence. Students who are pregnant or who have recently given birth are also eligible for reasonable accommodations.

Students are not required to take a leave of absence, withdraw, or limit their graduate studies because of pregnancy, childbirth or related medical conditions. However, students who are disabled due to pregnancy, childbirth and related medical conditions are eligible to take a pregnancy leave of absence. The Institute provides up to 6 weeks of pay to students during a pregnancy leave of absence; an additional 8 weeks of pay are available through family bonding leave (see following section).

A pregnant student who wishes to take a pregnancy leave should submit a pregnancy leave petition to the Graduate Office. Medical documentation from the student's treating health care provider may be required.

A student who chooses to take a leave of absence because they are pregnant or have recently given birth shall be allowed an additional period commensurate with the length of the leave, but not to exceed 12 additional months, to prepare for and take preliminary and qualifying examinations and an equal extension of time toward the normative time to degree while in candidacy for a graduate degree, unless a longer extension is medically necessary.

An enrolled student in good standing who chooses to take a leave of absence because they are pregnant or have recently given birth shall return to their program in good academic standing following an approved leave period up to one academic year, subject to the administrative requirements described above, unless there is a medical reason for a longer leave, in which case standing in the graduate program shall be maintained during that period of the leave.

The Institute also provides reasonable accommodations to pregnant students consistent with federal and state law. Reasonable

accommodations may include allowing pregnant students to maintain a safe distance from hazardous substances, allowing them to make up tests and assignments that are missed for pregnancy-related reasons or excusing of absences that are medically necessary. If in Caltech housing, students may remain while on pregnancy leave.

Bonding

Graduate students may take up to 8 weeks of family bonding leave with pay. An enrolled student in good academic standing who chooses to take a leave of absence because of the recent birth or adoption of his or her child may request a bonding leave by submitting a bonding leave petition to the Graduate Office for approval. Bonding leave is in addition to pregnancy leave, providing eligible students with a combined total of up to 14 weeks of paid leave. Students returning from an approved bonding leave shall return to his or her program in good academic standing following the leave, subject to the administrative requirements described above. If in Caltech housing, students may remain while on bonding leave.

Involuntary Leave

The Dean or designee may determine that it is necessary to place a student on an involuntary leave in a variety of circumstances, including when a student demonstrates behavior that poses a threat to health or safety, causes significant disruption to the Caltech community, for the personal safety or welfare of the student involved, as an interim measure, or as a result of a disciplinary action.

The Dean may impose an involuntary leave in appropriate circumstances, such as where a student's behavior: (1) has, or threatens to, cause significant property damage; (2) significantly disrupts the Caltech community; (3) presents a substantial risk of harm to self or others; (4) indicates the student is unable or unwilling to carry out self-care obligations; or (5) violates a Caltech policy or the honor system.

An involuntary leave also may be imposed when the student requires a level of care from the Institute community that exceeds the reasonable accommodations, resources and staffing that the Institute can reasonably be expected to provide for the student's well-being.

Review and Decision Process

If the conduct has been the subject of an investigation or review under an Institute process or procedure, the Dean will consider the findings and conclusions reached in that process. In other circumstances described above, in making an informed decision to place a student on involuntary leave, the Dean will conduct an individualized assessment and consider relevant information including information provided in a timely manner by the student. The Dean may consult with other Institute personnel, including but not limited to Security and Residential Life personnel, faculty, staff and other individuals or departments. If appropriate and feasible, the Dean may seek cooperation and involvement of parents or guardians of the student. Medical information, including medical information provided

in a timely manner by the student, may be considered if the behavior is associated with a physical or mental condition. In appropriate cases, the Dean may consult with the executive director of Student Wellness Services and/or require a physical or mental evaluation from a health professional if the Dean believes such an evaluation is necessary in order to make an informed decision. Students are expected, if necessary, to sign a release of information to facilitate discussions between Caltech and the health professional conducting the evaluation. The Dean will also consider whether relevant risk factors can be eliminated or reduced to an acceptable level through reasonable accommodation.

Written Decision

The student will be advised in writing of the decision to impose an involuntary leave. The Dean may stipulate conditions that must be met before the student may return. An involuntary leave may be a permanent separation from the Institute (i.e. expulsion); for a specific duration; or until certain conditions have been met. If the involuntary leave is not a permanent separation, the student will be advised of the length of the leave and/or any conditions for return.

Disciplinary Notations on Transcripts

If a student is ineligible to reenroll at Caltech due to the imposition of an involuntary leave, the Institute shall include on the student's transcript a notation stating that the student is ineligible to reenroll at Caltech because they have been subject to a disciplinary suspension or expulsion. A notation of expulsion is permanent, and a notation of suspension will remain on the student's record for seven years.

On request by the student, Caltech may remove from a student's transcript a notation of suspension if:

(1) the student becomes eligible to reenroll at Caltech; **or**

(2) the Institute determines that good cause exists to remove the notation.

Emergency Leave

If the Dean determines that a student's continued presence is likely to pose a substantial risk to the safety and well-being of the student or others, the Dean may place the student on an emergency interim leave before a final determination is made. The Dean will make reasonable attempts to meet with the student and consider relevant information, including in appropriate cases medical information provided by the student, before deciding on an emergency interim leave. An emergency interim leave will remain in effect until a final decision has been made.

Return from Leave

A student on involuntary leave will not be allowed to return until the Dean makes a fact-specific assessment of the circumstances, considers relevant risk factors, and concludes that the student does not pose a significant disruption to the functioning of the Institute community and/or does not pose a substantial risk to the health and safety of the student or others. The Dean will consider relevant

information, including information provided by the student. In cases where a student has a physical or mental condition associated with the behavior triggering the leave, the Dean will also consider whether the relevant risks can be eliminated by a reasonable accommodation. The student will be notified in writing if the Dean determines that the student will not be permitted to return from a leave or will be permanently separated from the Institute.

Appeal

A decision by the Dean to place a student on involuntary leave may be appealed in writing within ten days to the Vice President for Student Affairs (or designee). If the leave is imposed as a sanction resulting from a finding of responsibility under an Institute process, any applicable limitations on grounds for appeal will apply.

GUIDELINES FOR GRADUATE STUDENT ADVISING

The relationship between a faculty adviser and graduate student should be founded on mutual respect and open communication. Advisers and students should discuss the nature of their working relationship early and continue this discussion throughout their period of collaboration to ensure mutually understood and compatible expectations. These discussions should be frequent and open, and should include not only work, research goals, and performance reviews, but also change of status, time for personal and family responsibilities, time off, and concerns about academic or work situations. Both the student and adviser have the obligation to initiate meetings as necessary to ensure the success of the relationship.

After achieving candidacy, each Ph.D. student should be assigned a thesis advising committee consisting of a minimum of three professorial faculty members. This committee typically meets at least once a year beginning after candidacy or the fourth year of graduate study.

The graduate student-faculty adviser relationship should be guided by norms of fairness and professionalism. Both faculty and graduate students should avoid relationships that conflict with their respective roles and duties at Caltech. Both are bound by the prevailing policies prohibiting discrimination and harassment (Nondiscrimination Policy, Sex- and Gender-Based Misconduct, and Unlawful Harassment). Concerns relating to academic or work situations should be raised promptly between the persons directly involved, and handled informally if possible. Both students and advisers have the responsibility to raise and address concerns and conflicts promptly, honestly, and in a manner that conforms with academic integrity and professionalism. Caltech policy requires that students' concerns be addressed fairly and promptly, and prohibits retaliation or discrimination against students for appropriately voicing or raising a concern.

If a problem remains unresolved or if direct discussion is not possible, a student can seek assistance from division officers (e.g., option representatives) or the graduate deans. At any time, a student may request that discussions remain confidential. For more details

about sources of assistance, consult the graduate option regulations and the Student Problem Resolution Process.

PART-TIME PROGRAMS

Part-time graduate study programs at the Institute are for master's seeking graduate students who cannot devote full time to their studies and such students are subject to the following rules:

Degree Programs

- Applicants for the part-time master's program must submit a regular application form accompanied by a detailed plan for meeting the course requirements for the degree.
- Any research work done for academic credit shall be supervised by a Caltech faculty member.
- In general, students admitted to the part-time program are required to take at least 27 units of graduate course work and/or research each term.
- The part-time program is limited to two years of academic residence.
- Any option at the Institute retains the right to not participate in the program or to accept it under more stringent conditions.

Non-degree Programs

Caltech employees, both campus and JPL, are eligible to apply to take one or more graduate courses for credit. Participants in this program will not be considered to be working toward a Caltech degree, in contrast to the part-time program for graduate degrees described above, and courses taken under this program cannot be used to fulfill the requirements for a Caltech degree.

At least one month prior to the start of the term, the employee should have an initial discussion with the option representative of the option in which the course is to be taken. Application should be made to the Graduate Office by completing the special form provided for this purpose, and providing a transcript of academic work and a letter of recommendation. The employee must meet the prerequisites for the course, and must obtain the written permission of the instructor. The decision on admission to take each course will be made by the course instructor and the option representative, with final approval by the dean of graduate studies. Taking an additional course at a later time will require full reapplication. It is the employee's responsibility to arrange a revised work schedule with the appropriate supervisor and approval of the employee's supervisor is required.

Part-time non-degree students are subject to the Honor System and are under the purview of the dean of graduate studies. They may take only courses numbered 100 or higher and research courses are excluded from the program. For courses in which a letter grade is offered, these students may not register to receive a pass/fail grade in the course, nor can credit for the course be obtained by examination. The option may limit the number of non-degree students admitted to any one course.

RESPONSIBLE CONDUCT OF RESEARCH

Caltech researchers are expected to adhere to the highest professional standards in the conduct of research. Faculty members are charged by the Institute with the responsibility to safeguard the basic principles of research integrity, academic freedom, and public interest. Students are expected to also follow these same principles. When government funds are involved in the support of research, investigators are required to take specific steps to adhere to all rules and regulations of the government and sponsoring agencies. Students are required to have specific training in research ethics and integrity as well as conform to standards established by research supervisors or their laboratories. There are two situations in which this is mandated by federal law.

National Institutes of Health

Students that are funded through NIH grants, work with human or vertebrate animal subjects, or are required as part of their academic option's curriculum, have to meet a NIH requirement for training in specified areas as described in the Caltech Guide to Sponsored Research. In order to meet the NIH requirement, Caltech requires that all trainees supported by NIH funds take Biology course 252 "Responsible Conduct of Research."

National Science Foundation

Training in Responsible Conduct of Research is also required of students funded on NSF awards, including the GRFP program. In order to satisfy the NSF mandate, Caltech requires that students supported from NSF funds as described above shall take the online course on Research Ethics Education (CITI).

If a student can document having passed a similar, qualifying program at another institution, Caltech may accept that in lieu of completing Caltech's program. You must submit documentation in the form of a transcript or certificate to the Graduate Studies Office to receive credit for previous work. A passing grade in Bi 252 is an acceptable alternative to passing the CITI online Responsible Conduct of Research course.

CONFLICT OF INTEREST AND COMMITMENT OF GRADUATE STUDENTS

The Institute has a long-standing philosophy that all graduate students should be given the opportunity to be completely focused on graduate studies and research. This is one of the unique aspects of Caltech's graduate school and a key factor in the high level of productivity and accomplishment by our graduate students. To enable this, the faculty and Institute provide financial aid in the form of fellowships, tuition scholarships, graduate teaching, and research assistantships. The stipend and salary levels for students are modest but sufficient for economical students to live debt-free during their graduate studies. The financial support provided by the Institute and the requirements for continuous enrollment also enable almost all students to complete the degree programs in a timely manner.

In turn, the Institute expects that graduate students should be 100 percent committed to graduate studies while enrolled in a graduate program. Graduate students are expected to be continuously enrolled full-time, year-round, until they complete their degree program. In addition, graduate students should not accept employment, start or run a business, or engage in any activity inside or outside of the Institute that creates a conflict of commitment with their full-time, degree-seeking status.

Exceptions

There are some very limited exceptions to this policy. The Institute encourages extracurricular activities that provide service to the community and do not impact the student's academic progress or full-time status. The Institute also recognizes that some students desire to gain experience as instructors or work in an educational or research setting outside of Caltech.

Outside Employment

Students must have the approval of their adviser, the option representative, and the dean of graduate studies in order to engage in any outside employment activities. Approval is contingent on demonstrating that outside work does not compromise the full-time commitment to graduate studies. Once permission is granted, students may engage in employment of up to one day per week (8 hours) for a limited-duration for these purposes (see Financial Assistance).

Students must declare to the dean of graduate studies all external funding, including fellowships, awards, or employment, part- or full-time. The Institute may adjust Institute financial aid accordingly to maintain the stipend within the Institute guidelines and to recover tuition from outside sources whenever possible. A student's financial aid and/or Institute salary may be reduced if the income is significant. In the case of long-term, unreported employment activities, the student may be asked to repay financial aid. Students may not hold a position of line responsibility in an outside enterprise for pay or profit.

International students on a visa are further required to consult with the office of International Student Programs to determine eligibility. Students must provide official documentation of the financial award or salary, as well as submit a request to the Graduate Office before accepting any employment. Permission to engage in outside employment is contingent on the student maintaining satisfactory academic progress as determined by the dean of graduate studies in consultation with the adviser and option representative.

Non-Paid Activities

Students must have the approval of their adviser, the option representative, and the dean of graduate studies in order to engage in or continue in any outside activities wherein the time committed to those activities may impact the student's progress toward completion of degree requirements.

Leave of Absence
Students who work full-time off campus in a commercial organization are expected to take a personal leave of absence. They will not be enrolled during this time, and the "clock" will stop on their graduate career. Taking a personal leave in order to work requires the endorsement of the adviser and permission of the dean of graduate studies. A personal leave is always required when the job is not directly related to thesis research. Students who need to stop their studies to address health issues should take a medical leave of absence, which requires the endorsement of Student Wellness Services as well as the permission of the dean of graduate studies.

Detached Duty
In some cases, a student may be engaged in research at an external laboratory or research institute under the supervision of a Caltech faculty adviser, and conducting research that is directly related to their degree program. Another situation is that a student may be invited to be a visiting researcher at another university, or the student may need to be working with a faculty member who has left Caltech and is working at another institution.

Students may go on detached duty rather than on leave of absence if the adviser and dean of graduate studies approve and there is documentation of a research program integral to their thesis project and appropriate mentoring. Students on detached duty should have completed their residency requirements and advanced to candidacy prior to moving to the host institution.

The student should submit the documentation and a petition form to the Graduate Office. Students on detached duty are still enrolled as full-time students but are in residence at another location. They may be paid by Caltech or through another organization. It is the student's responsibility to continue to be in good standing, and registered and in full-time status while on detached duty. Detached duty petitions are usually valid for a limited time, less than one year, and may be renewed upon request.

Consulting and Other Entrepreneurial Activities
Graduate students are sometimes approached to perform paid consulting or are inspired to be entrepreneurs. In these cases, students have to be exceptionally careful not to create conflicts of commitment or conflicts of interest through these activities. Students considering these activities should familiarize themselves with the Caltech policies on conflict of interest, outside employment or business activity, and the Caltech ethics handbook. Students may not engage in any consulting activities that interfere with their primary graduate student activities of learning and research. Scrupulous care must be taken to ensure that Caltech's name and its letterhead are used neither directly in any correspondence between the student and the company the student wishes to consult for, nor in any reports that student may submit to the company.

Of particular concern are students consulting or accepting employment from a company in which their adviser or other Caltech

faculty member is directing a student's research and has a significant interest or is a paid consultant. In such cases, the division chair must approve any student involvement in the activities performed for the company. The student must submit a written disclosure, and a conflict management plan will be put in place.

Graduate students should not enter into any consulting or employment agreement with intellectual property encumbrances or confidentiality provisions that are in conflict with the student's commitments to Caltech or that may compromise academic progress.

Please refer to the Graduate Office website for the complete policy and regulations regarding conflicts of commitment and interest. If there are any questions about the propriety of any outside activity or agreements, this should be discussed with the Graduate Office and, if necessary, the Office of Research Compliance and the Office of the General Counsel.

WORKING AT SPECIAL LABORATORIES

Students who desire to take advantage of the unique opportunities available at one of the special laboratories (e.g., JPL) for Ph.D. thesis work may be allowed to do so provided that they maintain good contact with academic life on campus, the laboratory involved commits financial support for the duration of the thesis research, and all Caltech graduate thesis research carried out at a special laboratory is under the supervision of Caltech faculty members.

Students' requests to carry out thesis work at a special laboratory should be formally endorsed by the appropriate committee of their option and by the special laboratory, on a petition submitted through the option representative to the dean of graduate studies. The special laboratory should recognize its commitment of special equipment or any other resources required for the thesis work. Approval by the special laboratory should also indicate that the thesis topic is a sensible one, and that it is not likely to be preempted by the laboratory.

A student may take similar advantage of unique opportunities at a corporate or governmental research and development facility under the same conditions, providing that there exists a formal written agreement between the R&D facility and the student's thesis adviser, and that advance written approval is obtained from the dean of graduate studies. Such training may in some cases involve full-time employment at the laboratory for a limited period of time for the purpose of engaging in the essential data collection that is integral to a student's thesis. Typically, such students who are not in a local laboratory are placed on detached duty status.

Employment by a special laboratory of a graduate student for work not connected with the thesis should be regarded as equivalent to other outside employment.

EXCHANGE PROGRAM WITH SCRIPPS INSTITUTION OF OCEANOGRAPHY

An exchange program with the Scripps Institution of Oceanography (SIO), University of California, San Diego, permits Caltech graduate students to enroll in and receive credit for graduate courses offered by SIO. Arrangements should be made through the student's major option and the Graduate Office. The student must obtain the advance approval of the instructors of courses to be taken at SIO. In some cases, arrangements may be made for the student to be temporarily in full-time residence at SIO.

Thesis research done partly at SIO may be arranged directly by the student's option and the staff of the appropriate research laboratories at SIO, without the necessity of enrolling for SIO courses designated for research; in this case the student will continue to be under the supervision of the Caltech thesis adviser and will enroll for Caltech research units.

GENERAL REQUIREMENTS FOR GRADUATE DEGREES

DEGREE OF MASTER OF SCIENCE

The Master of Science degree is a professional degree designed to prepare a student for teaching, for further graduate studies, or for more advanced work in industry. Detailed requirements are based primarily on professional studies, and the program should be planned in consultation with the faculty in the appropriate discipline. Under normal circumstances, the requirements for the master's degree can be completed in one academic year. Students must declare candidacy for the master's degree no later than the academic year in which the final degree requirements have been met or upon separation from the Institute. Students who are pursuing a doctoral degree and obtain a master's along the way, must declare candidacy for the master's no later than two weeks prior to conferral of the Ph.D.

A student who enters the Institute holding a master's degree from another institution will not normally be awarded a second master's degree in the same field. A student will not be awarded two master's degrees from the Institute.

Special regulations for the master's degree are listed under each graduate option. Several options do not offer a master's degree except in special circumstances.

Residence and Units of Graduate Work Required

At least one academic year of enrollment at the Institute and a minimum of 135 units of graduate work at the Institute subsequent to the baccalaureate degree are required for the master's degree. Included in these units are at least 27 units of free electives or of required studies in the humanities numbered 100 or above. Advanced courses taken while enrolled as a Caltech undergraduate student in

excess of the bachelor's degree requirements may be counted toward the master's degree requirements with the approval of the academic Option Representative and the Dean of Graduate Studies.

To qualify for a master's degree, a student must complete the work indicated in the section on special regulations for their option with a grade-point average for the approved master's candidacy courses of at least 1.9.

In special cases, with the approval of the instructor, option representative, and the Dean of Graduate Studies, courses taken elsewhere before enrollment at the Institute may be offered in place of specifically required courses. An examination may be required to determine the acceptability of such courses. Course credit, if granted, shall not count toward the 135-unit and residency requirements.

Admission to M.S. Candidacy

By the third term of the academic year in which the student expects to receive the degree, candidates should have completed a plan of study in Regis, which must have the approval of the option representative and, in some cases, of the research adviser. This approved plan of study will constitute requirements for the degree. Any modifications to the plan of study must be approved by the Option Representative no later than two weeks before the degree is to be conferred. Some options require a thesis or research report in addition to course requirements. The thesis or research report must be approved by the research adviser and option representative no later than two weeks before the degree is to be conferred. For additional information and option-specific requirements, please refer to the section "Special Regulations for Graduate Options."

Joint B.S./M.S. Degree

In exceptional cases, undergraduate students may be eligible to pursue a joint B.S./M.S. program of study to be completed within the four years (12 terms) of the undergraduate program. The M.S. degree may be in a different field than the B.S. option. Students should contact the respective graduate Option Representative to find out if the joint B.S./M.S. degree is offered in a particular option by the start of junior year. If so, students must follow the normal procedures for admission to the graduate program. Students admitted to the joint B.S./M.S. degree must complete a minimum of 486 units for the bachelor's program and an additional 135 units for the master's program with no overlapping of courses. In addition, a written plan of study must be submitted to the Registrar's Office for approval no later than the fall term of the senior year. The plan of study should provide detail of the courses that are proposed to satisfy each degree requirement within the 12 terms of the bachelor's program and once approved shall constitute the requirements for the degree. Additional terms and overloads are not permitted. Any changes to the plan require written approval by the Registrar. If not completed within the four years, students will be removed from the joint program and they, and all their courses, will be attached to the bachelor's program. Students enrolled in the joint B.S./M.S. degree will be considered

undergraduate students and will not be eligible for graduate financial aid, graduate housing, or other graduate student privileges.

ENGINEER'S DEGREE

Engineer's degrees are awarded in exceptional circumstances. The work for an engineer's degree must consist of advanced studies and research in the field appropriate to the degree desired. It must conform to the special requirements established for that degree and should be planned in consultation with the members of the faculty concerned. Students who have been admitted to the terminal master's degree and wish to pursue further studies leading toward either the engineer's or the Ph.D. degree must file a petition (and in some cases must file a new application) to continue graduate work toward the desired degree. Students who have received an engineer's degree will not be admitted for the Ph.D.

Residence

At least eight terms of graduate academic enrollment subsequent to a bachelor's degree equivalent to that given by the Institute are required for an engineer's degree. Of these, at least three terms must be at Caltech. It must be understood that these are minimum requirements, and students must often count on spending a somewhat longer time on graduate work.

To qualify for an engineer's degree, a student must complete the work prescribed by the supervising committee with a grade-point average of at least 1.9. Research work and the preparation of a thesis must constitute no fewer than 55 units. More than 55 units may be required by certain options, and the student should determine the particular requirements of their option when establishing a program.

Admission to Candidacy

Before the midpoint of the first term of the academic year in which the student expects to receive the degree, they must complete a proposed plan of study and, in consultation with the chair of the appropriate division, will select a committee comprised of at least three members of the professorial faculty to supervise the student's work and to certify its satisfactory completion. The student should consult with this committee in planning the details of their work. The plan of study shall then constitute the requirements for the degree. Any modifications must be approved by the Option Representative at least two weeks before the degree is conferred.

The student will be admitted to candidacy for the degree when the supervising committee certifies (a) that all the special requirements for the desired degree have been met, with the exception that certain courses of not more than two terms in length may be taken after admission to candidacy; (b) that the thesis research has been satisfactorily started and can be finished at the expected date; (c) that the candidate demonstrates competence in oral and written English.

Admission to candidacy should be obtained by the midpoint of the term in which the degree is to be granted, but no later than the academic year in which the final degree requirements have been met

or upon separation from the Institute.

Thesis
Engineer's degree candidates are required to upload a final thesis by June 1 in the year the degree is to be conferred in accordance with the same regulations that govern the preparation of doctoral dissertations. These regulations may be obtained from the Graduate Office website.

The use of "classified'' research as thesis material for any degree will not be permitted. Exceptions to this rule can be made only under special circumstances, and then only when approval is given by the Dean of Graduate Studies before the research is undertaken.

Examination
At the discretion of the option in which the degree is desired, a final examination may be required. This examination would be conducted by a committee appointed by the candidate's supervising committee.

DEGREE OF DOCTOR OF PHILOSOPHY

The degree of Doctor of Philosophy (Ph.D.) is conferred by the Institute primarily in recognition of breadth of scholarship, depth of research, and the power to investigate problems independently and efficiently, rather than for the completion of definite courses of study through a stated period of residence. The work for the degree must consist of research and the preparation of a thesis describing it, and of systematic studies of an advanced character, primarily in science or engineering. In addition, the candidate must have clear self-expression in both oral and written English.

Subject to the general supervision of the Committee on Graduate Study, the student's work for the Ph.D. degree is specifically directed by the division in which they have chosen the major subject. Each student should consult with their division concerning special divisional and option requirements.

Admission
With the approval of the Dean of Graduate Studies, students are admitted to graduate standing by the option in which they choose their major work toward the Ph.D. degree. In some cases, applicants for the Ph.D. may be required to complete requirements for the master's degree first; however, this is not a general prerequisite for the Ph.D. Students who have received an engineer's degree will not be admitted for the Ph.D. degree.

A student who holds a Ph.D. or the equivalent from another institution will not normally be admitted to graduate standing at Caltech to pursue a second Ph.D. degree. A student will not normally be awarded two Ph.D. degrees from the Institute.

Minor Programs of Study

The Institute does not require a minor for the Ph.D. degree, but the individual options may have minor requirements as part of their requirements for the major.

A doctoral student may undertake a minor program of study in most options as specified in this catalog under the section "Special Regulations of Graduate Options." Completion of a minor program of study is recognized on the diploma by the statement "…and by additional studies constituting a minor in [name of option]."

A minor program of study should be at a level of study in the minor substantially beyond that typically acquired by students as part of their major requirements. Most options require 45 units or more, including at least one 200-level course and a coherent program of the supporting 100-level courses. The faculty of the minor option may approve a proposed minor program on the basis of overall class performance and/or by an oral examination.

Detailed requirements for minor options are listed under the individual options. Students cannot use courses required by their major option in fulfillment of the minor requirement.

Academic Enrollment

At least three academic years (12 terms) of academic enrollment subsequent to a bachelor's degree equivalent to that given by the Institute are required for the Ph.D. Of this, at least one year (4 terms) must be at the Institute. It should be understood that these are minimum requirements, and students must usually count on spending a somewhat longer time in work for the degree. A student whose undergraduate work has been insufficient in amount or too narrowly specialized, or whose preparation in their special field is inadequate, should plan upon spending increased time in work for the degree.

However, no student will be allowed to continue work toward the Ph.D. degree for more than six academic years (24 terms) of graduate enrollment, without an extended registration petition approved by the Dean of Graduate Studies.

Registration

Continuity of registration must be maintained until all requirements for the Ph.D. have been completed, with the exception of authorized leaves. Registration is typically required for the term in which the thesis defense is undertaken.

Thesis Advisers and Committee Chairs

The thesis adviser must be a full-time, tenured or tenure-track faculty member. Research faculty, emeritus faculty, and Faculty Associates (in some graduate options only) can supervise thesis research; however, the thesis adviser of record must be a tenured or tenure-track Caltech faculty member. In such cases, responsibilities of the adviser of record include general advising, monitoring student progress, and meeting with the student at least twice a year. Expectations for the relationship between graduate students and faculty advisers are discussed under Guidelines for Graduate Student Advising.

Progress through the graduate program is monitored in part by the candidacy, thesis advisory, and thesis examination committees detailed in the following sections. Each committee has a chair who is responsible for running the meeting, summarizing the outcome, and working with the graduate student and adviser as appropriate. The chair of each committee is a professorial faculty member distinct from the adviser.

Admission to Candidacy

On the recommendation of the option concerned, the Dean of Graduate Studies will admit a student to candidacy for the degree of Doctor of Philosophy after the student has been admitted to work toward the Ph.D. and has been enrolled for at least one term; has initiated a program of study approved by the major option and, if needed, by the minor option; has demonstrated, by written or oral examination, a comprehensive grasp of the major and minor subjects and of subjects fundamental to them; has displayed the ability for clear self-expression in both oral and written English; and has shown ability in carrying on research in a subject approved by the option concerned. Option regulations concerning admission to candidacy are given in a later section.

Depending upon option regulations, candidates will either be assigned a candidacy committee by the Option Representative or must independently select appropriate members to serve on the candidacy committee. A candidacy committee consists of a minimum of three members, two of whom must be professorial faculty. Emeritus faculty, research faculty, JPL staff and external scholars may serve on the candidacy committee, with approval of the Option Representative and the Dean of Graduate Studies in advance of the candidacy examination. The student should ensure that all members of the committee are available during the examination period and that they are willing to provide timely and appropriate feedback.

A student not admitted to candidacy by the end of the third year or twelfth term of graduate enrollment at the Institute must petition the Dean of Graduate Studies for permission to register for further work. Approval of the petition for extended registration requires a plan to complete the candidacy exam and any outstanding coursework within two terms.

Candidacy (and permission to register) may be withdrawn by formal action of the option from a student whose research is not satisfactory, or for other compelling reasons. However, the option must petition through its Division Chair to the Dean of Graduate Studies before taking such action.

Thesis Advisory Committee

Each Ph.D. student is assigned a Thesis Advisory Committee consisting of a minimum of three professorial faculty members. Emeritus faculty, research faculty, JPL staff and external scholars may serve on the thesis examination committee with approval of the option representative and the Dean of Graduate Studies. Following candidacy, or by the fourth year of graduate study, a student will have

an annual meeting as specified by the option with either the thesis advisory committee, the committee chair, or the option representative (if not the adviser), to discuss progress towards completing the thesis and future plans.

Thesis Examination

Each Ph.D. candidate shall undergo broad oral examination on the major subject, the scope of the thesis, and its significance in relation to the major subject. The thesis examination, subject to the approval of the Dean of Graduate Studies, may be taken after admission to candidacy whenever the candidate is prepared; however, it must take place at least three weeks before the degree is to be conferred.

The thesis examination may be written in part and may be subdivided into parts or given all at one time at the discretion of the options concerned. The student must declare their intent to defend by posting the exam details in Regis not less than two weeks before the date of the examination. A thesis examination committee consists of four members, with a minimum of three professorial faculty. Emeritus faculty, research faculty, JPL staff and external scholars may serve on the thesis examination committee with approval of the Option Representative and the Dean of Graduate Studies in advance of the thesis examination.

Thesis

At least two weeks before the final oral examination, the candidate is required to provide a draft copy of the completed thesis to the Graduate Office for proofreading as well as to the members of the thesis examination committee. The date of the examination and the composition of the thesis examination committee should be posted in Regis at least two weeks before the final defense is scheduled. In general, registration is required for the term in which the thesis defense is undertaken. Approval of the Dean of Graduate Studies is required for any student seeking to enroll for a subsequent term following the thesis defense. This enrollment will be limited to one term and cannot be granted after the degree has been conferred. A student not receiving Caltech funding, may petition the Dean of Graduate Studies for a tuition waiver if the student schedules the examination by the third Friday of the term in which the examination will be taken.

Before uploading the final, corrected thesis to CaltechTHESIS, it is the candidate's responsibility to obtain approval of the thesis by the Option Representative and all members of the thesis examination committee.

The final version of the thesis must be uploaded to CaltechTHESIS by June 1 in the year that the degree is to be conferred. Students who cannot meet this deadline are required to petition the Dean of Graduate Studies for an extension to keep the thesis active. In such cases, the degree would be conferred in the following year's commencement. It is required that all Ph.D. candidates submit an electronic copy of their dissertation, which the Caltech Library will then archive and make available online as part of the Networked Digital Library of Theses and Dissertations (NDLTD), an international

organization that allows researchers to globally search a database of electronic theses and dissertations. For special option regulations concerning theses or the exam composition, see specific graduate options.

With the approval of the option concerned, a portion of the thesis may consist of one or more articles published jointly by the candidate and members of the Institute staff or other coauthors. In any case, however, a substantial portion of the thesis must be the candidate's own exposition of their own work.

The use of "classified'' research as thesis material for any degree is not permitted. Exceptions to this rule can be made only under special circumstances, and then only when approval is given by the Dean of Graduate Studies before the research is undertaken.

Regulations and directions for the preparation of theses may be obtained from the Graduate Office website and should be followed carefully by the candidate. Thesis templates are also available at https://library.caltech.edu/theses, as is information regarding thesis deposits, embargo policies and copyright issues.

SATISFACTORY ACADEMIC PROGRESS

To continue in a degree program, graduate students must maintain satisfactory academic progress, as defined in this section. In addition, graduate students must comply with Institute policies and codes of conduct to remain in good standing.

General Guidelines

Graduate students must continuously maintain a full-time program of study and research in each of the four terms during the year (including summer) until all degree requirements have been completed, unless a leave of absence is granted. Students who do not enroll continuously or do not enroll upon expiration of a leave of absence are separated from the Institute. Enrolled students are expected to be in person and approval by the Option and Dean of Graduate Studies is required for remote enrollment.

A full-time program of study consists of enrollment in 36 units per term, including research units. Many options require a minimum grade in particular courses or groups of courses. If this grade requirement is not met, a limited number of courses may be repeated and would count toward the 36-unit-per-term requirement. Approval by the Dean of Graduate Studies is required before dropping any course that brings a student below 36 units. The treatment of incomplete grades and withdrawals is specified in Grades and Grading. Satisfactory academic progress is monitored each academic term by the Graduate Studies Office.

The Master of Science degree requires at least three terms in person at the Institute and a minimum of 135 units of graduate work with a grade-point average of at least 1.9. The master's degree is limited to two years unless a petition is approved by the Dean of Graduate Studies.

The degree of Engineer consists of advanced studies and research and requires at least eight terms of enrollment with a grade-point

average of at least 1.9. The engineer's degree is limited to 12 terms unless a petition is approved by the Dean of Graduate Studies.

The Doctor of Philosophy degree consists of advanced studies and research, primarily in science or engineering, under the guidance of an adviser, and the preparation and defense of a doctoral thesis. At least 12 terms of enrollment are required with a grade-point average of at least 1.9. The typical Ph.D. can be completed in six years or less and is limited to 24 terms unless an extended registration petition is approved by the Dean of Graduate Studies. A doctoral student who has not been admitted to candidacy within 12 terms must petition the Dean of Graduate Studies for extended registration. Petitions for extended registration for candidacy must include a plan and schedule for completion of candidacy within two terms, agreed upon and signed by the student, the student's thesis adviser, and the Option Representative. Students who fail to complete candidacy within the two terms may be placed on academic probation and will not be allowed to enroll without a scheduled candidacy date with their advisory committee.

Advising and Communication

All doctoral students must have a thesis adviser to remain in good academic standing. The timeline for securing a thesis adviser varies by the specific graduate option (see Special Regulations for Graduate Options). A student's thesis adviser must be an active member of the Caltech professorial faculty and is responsible for general advising, approving and guiding a research topic, monitoring the student's progress until all degree requirements have been met, and in most cases, providing financial support for the duration of the degree program.

Students are expected to communicate and interact with their adviser on a regular and timely basis regarding academic progress. Students are also expected to respond in a timely manner to official communications from the Graduate Studies Office or their academic Option (i.e., the Dean, Associate Dean, Assistant Dean, Option Representatives, Option Managers, other graduate program administrators, committee members, and other faculty members). Failure to do so may result in referral to the Dean of Graduate Studies for possible corrective action.

Determination of Satisfactory Academic Progress

Satisfactory academic progress is judged by the Options against the guidelines set in Special Regulations for Graduate Options in the Institute Catalog for the year of initial enrollment. These guidelines typically detail the following requirements, along with a timeline: completion of specific courses, oral and/or written examinations, advancement to candidacy, securing of a thesis adviser, and research requirements. For students failing to meet Option guidelines, revocation of permission to enroll may be recommended by the Option to the Dean of Graduate Studies. Further, even after advancement to candidacy, permission to enroll may be denied by formal action of an Option due to unsatisfactory research performance, failure to secure

or maintain a thesis adviser, or other compelling reasons. However, the Option must petition through its Division Chair to the Dean of Graduate Studies before taking such action.

Failure to achieve the expectations above may result in academic probation or disciplinary action, including separation from the Institute. A decision to revoke permission to enroll may be appealed in writing within ten days to the Vice President and Faculty Dean of Students or designee.

Good Standing
A student is in good standing if they meet standards for Satisfactory Academic Progress and program and research requirements and are not currently on any probationary status.

Academic Probation
The graduate deans, in consultation with a student's academic adviser and/or division, can place a student on academic probation for failure to meet the written expectations for Satisfactory Academic Progress. A student will remain on academic probation until they meet expectations as discussed with and outlined by the graduate deans.

GRADUATE EXPENSES

The tuition and fees charge for all students registering for graduate work is currently $68,001.00 per academic year, payable at the beginning of each term, Fall (9/29/2025), Winter (1/5/2026), and Spring (3/30/2026). Graduate students who cannot devote full time to their studies are allowed to register only under special circumstances. Students desiring permission to register for fewer than 36 units must therefore petition the dean of graduate studies for an underload.

The payment of tuition by graduate students is required (a) without reference to the character of the work by the student, which may consist of research, independent reading, or writing a thesis or other dissertation, as well as attendance at regular classes; (b) without reference to the number of terms in which the student has already been in residence; and (c) without reference to the status of the student as an appointee of the Institute, except that members of the academic staff of rank of instructor or higher are not required to pay tuition.

Unpaid Bills
All bills owed the Institute must be paid when due. Any student whose bills are past due may be refused registration for the following term. All graduate students with an outstanding bursar's bill balance of $1,500.00 or more will have a hold placed on their registration for the subsequent term the day before online registration opens. The hold will be released once payment reducing the balance to less than $1,500 has been cleared by the Institute's bank, which typically occurs 3-5 business days after payment is initiated through Transact/CASHNet. Diplomas will not be released until the bursar's account is paid in full.

Caltech ID Card Charges
If a graduate student owes more than $1,500.00, the student's charging privileges will be suspended. Charging privileges will be reactivated once students have paid their bill in full with the Bursar's Office.

EXPENSE SUMMARY 2025-2026

General:		
	Tuition and fees	$68,001.00
Other:		
	General Deposit	$100
	Books and supplies (approx.)	$1,428.00
	Contact Bursar's Office for audit fee.	
Furnished Catalina Apartments (Annual License Contract):		
4 bedroom apt. $790.00 per person per month (plus utilities)		
2 bedroom apt. $940.00 per person per month (plus utilities)		
1 bedroom apt. $1,585.00 per apt. per month (plus utilities)		
Studio apt. $1,195.00 per apt. per month (plus utilities)		
Unfurnished Off-Campus Apartments (Annual License Contract):		
2 bedroom apt. $1,765.00 per apt. per month (plus utilities)		
1 bedroom apt. $1,315.00 per apt. per month (plus utilities)		
The Institute also has a catalog of unfurnished apartments and single family homes available for lease at varying rental costs based on size. Additional information		
Fees are subject to change at the discretion of the Institute.		

Fees for Late Payment
A $50.00 late fee penalty will be charged by the Bursar's Office for failure to clear a past-due account at the beginning of each term.

Fees for Late Registration
Registration is not complete until the student has registered for a program approved by their adviser and has paid tuition and other fees. A penalty fee of $50 is assessed for failure to register within five days of the scheduled dates.

Honor System Matters
Monies owed to the Institute resulting from a disciplinary matter may be collected through the Bursar's Office, at the request of the dean of graduate studies.

Housing Facilities
The Catalina Central complex provides approximately 152 single rooms in four-bedroom furnished units. Another, Catalina North, has 156 single rooms in two-bedroom furnished units, and Catalina South has 78 single rooms in two-bedroom furnished units, and 29 one-bedroom furnished units. These apartments are also available to married or partnered students.

Rates for housing vary, depending upon the accommodations and services provided. A contract is required to live in these houses for the academic year.
Complete information here.

There is one Residential Life Coordinator (RLC) and four Resident Associates (RAs) in the Catalina Complex. An RLC is a specially trained full-time university employee, specializing in college student development, community building, counseling, and crisis intervention. The RLC supervises the RAs on programming and overall student wellness. The RLC also assists Housing with the management and daily operations of the complex. There are also Catalina Community Associates (student volunteers) who work with the RLC and RAs on programming and community building in the Catalinas.

The Institute also owns a limited number of apartments and single-family houses that are available for rental, on a lease basis, to single or married/partnered graduate students or graduate students with families. Because of limited availability, there is a waiting list for these properties. Additional information and application.

Students preferring to live in non-Institute housing typically pay approximately $1,100 to $1,400 per month/each, in rent for a shared apartment, and somewhat more for a private apartment. Please note that the Institute cannot make negotiations for individual housing off campus.

Dining Facilities
Graduate students are granted the privilege of joining the Athenaeum (faculty club), which affords the possibility of contact with fellow graduate students and with others using the Athenaeum, including the Associates of Caltech, distinguished visitors, and members of the professional staffs of the Huntington Library and the Caltech.

Caltech Dining Services operates several eateries located on campus for breakfast, lunch and dinner. See Dining Locations

Health Services
Health services available to graduate students are explained in section one of this Catalog.

FINANCIAL ASSISTANCE

Caltech offers in each of its options a number of fellowships, tuition scholarships, and graduate assistantships. In general, tuition scholarships may be for full or partial tuition charges; assistantships provide stipends; and fellowships often provide both tuition scholarship awards and stipends. Graduate assistants are eligible for tuition awards. Appointments to fellowships, scholarships, and assistantships are decided yearly by the student's academic option.

Graduate students receiving any form of financial award from the Institute are required to report to the dean of graduate studies any financial aid from other sources. With prior written approval from the dean of graduate studies, students may be allowed to accept outside employment of no more than 8 hours per week if there is no conflict of interest and the time commitment does not interfere with their graduate studies. All outside employment must be reported to the dean of graduate studies.

GRADUATE ASSISTANTSHIPS

Graduate assistants help with teaching, laboratory work, or perform research of a character that affords useful academic experience while permitting a full academic schedule of courses. The specific research and teaching obligations of graduate assistants are agreed upon with the adviser.

Caltech graduate students often receive a combination of teaching and research assistantships; however, the total work commitment cannot exceed 20 hours per week during the academic year. Summer appointments can be greater, with assignments up to 40 hours per week. A graduate student who undertakes activities related to the Institute aggregating more than 62 hours per week (in class, research assistantship, and teaching assistantship hours) must petition the dean of graduate studies.

Graduate assistant stipends are based on four quarters paid monthly throughout the year. Students are also entitled to two weeks of annual vacation and Institute holidays. Students should prearrange their vacation schedule with their adviser. When necessary, graduate assistants may arrange for medical leave, pregnancy leave, bonding leave, or personal leave. Any questions should be referred to the dean of graduate studies.

Teaching Assistantships

A full teaching assistantship usually requires 20 hours per week to be devoted to teaching and to the related activities of class preparation, grading, and consulting with students. In general, teaching obligations are confined to the 12 weeks of the academic terms, excluding summer. A student may not be a teaching assistant for a course in which they are enrolled. Only teaching assistants with good oral English and who have fulfilled the Institute English proficiency requirement are permitted to teach sections.

All teaching assistants, including undergraduate students with teaching responsibilities, are required to attend teaching-assistant

training before payment can be processed. Training sessions are conducted by the Center for Teaching, Learning, and Outreach (CTLO) and occur in the first week of the fall term, typically during orientation, and at least once per term.

Teaching assistants must familiarize themselves with Caltech's policy on Unlawful Harassment and follow other policies related to teaching discussed in the required training. Classes should foster academic achievement in a "hassle-free" environment. Teaching assistants should not attempt to date a student in their class, and should disqualify themselves from teaching a section in which a spouse or current partner is enrolled.

Please see the Graduate Studies Office for additional policies information at www.gradoffice.caltech.edu/financialsupport/assistantships.

Research Assistantships

Research assistantships typically are 20 hours per week during the academic year, but can be as much as 40 hours per week during the summer. The specific duties are decided upon by the adviser.

Graduate Scholarships, Fellowships, and Research Funds

The Institute awards endowed fellowships and scholarships for tuition and/or stipends to graduate students of exceptional ability. Students are also strongly encouraged to apply for scholarships and fellowships from federal and private agencies and organizations to support their graduate studies.

Loans

Several types of loans are available to graduate students. To qualify for any of these, a student must demonstrate financial need and must maintain satisfactory academic progress in the course of study for which they are enrolled. Application forms and further information are available from the Financial Aid Office.

Refund and Repayment Policy

Caltech has established an equitable refund policy for students who find it necessary to withdraw or take a sabbatical from the Institute.

Students who officially withdraw or take a sabbatical from the Institute during an academic term may receive a tuition refund. Students living in Caltech housing may also be eligible for a partial refund from the Housing Office.

When granting refunds to financial aid recipients or graduate assistants, it is Caltech's policy to return the refund, in most cases, to the original account.

PRIZES AND AWARDS

THE CALTECH Y ADVOCATING CHANGE TOGETHER (ACT) AWARD

The Caltech Y Advocating Change Together (ACT) Award provides students with the opportunity to learn about a global, national, or local issue by immersing themselves with activists working on a cause.

AMORI DOCTORAL PRIZE IN CMS

Established in 2017 by Michael Amori (MS '07), this prize honors outstanding dissertations in the computing and mathematical sciences during the current academic year. Awardees are selected by a committee of computing and mathematical sciences faculty each spring.

APOSTOL AWARD FOR EXCELLENCE IN TEACHING IN MATHEMATICS

Named in honor of Tom Apostol, who taught at Caltech for over 50 years, this award recognizes excellence in teaching by graduate and undergraduate teaching assistants in mathematics.

CHARLES D. BABCOCK AWARD

Voted on by members of the aeronautics faculty, this award is given to a graduate student whose achievements in teaching or other assistance to students have made a significant contribution to the aeronautics department.

WILLIAM F. BALLHAUS PRIZE

This prize recognizes aeronautics students for outstanding doctoral dissertations.

THE BHANSALI FAMILY PRIZE IN COMPUTER SCIENCE

Established in 2001 by Vineer Bhansali (B.S. '87, M.S. '87) in memory of his grandfather, Mag Raj Bhansali, this prize is given to an undergraduate student for outstanding research in computer science in the current academic year. Awardees are selected by a committee of computer science faculty.

BHANSALI FAMILY DISSERTATION PRIZE IN COMPUTER SCIENCE

Established in 2018 by Vineer Bhansali (B.S. '87, M.S. '87) in memory of his grandfather, Mag Raj Bhansali, this prize is given to honor outstanding dissertations in computer science, broadly defined, during the current academic year. Awardees are selected by a committee of computer science faculty each spring.

ROLF D. BUHLER MEMORIAL AWARD IN AERONAUTICS

This award is given to an aeronautics student for outstanding academic achievement in the master's program.

THE CALTECH Y RISE SERVICE AWARD

The Caltech Y Rise Service Award recognizes exceptional service provided by Rise Program tutors. This award highlights the dedication and outstanding contributions of individuals who exemplify the Caltech Y's commitment to service.

IAN CAMPBELL AWARD

The Ian Campbell Award is for outstanding performance in field geology courses during this academic year.

W. P. CAREY & CO., INC., PRIZES IN APPLIED MATHEMATICS

Established by William P. Carey and W. P. Carey & Co., Inc., this prize is awarded to outstanding doctoral dissertations in applied mathematics in the current academic year. Awardees are selected by a committee of applied mathematics faculty.

THE CCID ACTIVIST SCHOLAR AWARD

This award is given to individuals who demonstrated excellence within their discipline and research while engaging in complex social justice issues. This awardee has led or participated in advocacy campaigns centering on the experiences of minoritized identities and provided vision and leadership in forming affinity spaces and targeted support programs.

THE CCID AGENT OF CHANGE AWARD

This award is given to individuals embodying servant leadership through a demonstrated commitment to steering institutional change within the Caltech community. This person takes the initiative and has the vision to translate a need into actionable steps or policy to create a legacy and a more inclusive campus climate.

CENTENNIAL PRIZE FOR THE BEST THESIS IN MECHANICAL AND CIVIL ENGINEERING

This prize, awarded annually to a Ph.D. candidate in applied mechanics, civil engineering, or mechanical engineering, is given to a student whose doctoral thesis is judged to be the most original and significant by a faculty committee appointed annually by the executive officer for mechanical and civil engineering. This prize was established with gifts from alumni following the Mechanical Engineering Centennial Celebration in 2007.

RICHARD BRUCE CHAPMAN MEMORIAL AWARD

This award is given to a graduate student in hydrodynamics who has distinguished themselves in research in the Division of Engineering and Applied Science.

BEN P.C. CHOU DOCTORAL PRIZE IN IST

This prize recognizes outstanding doctoral dissertations in the broad area of information science and technology. The prize was established by Ben P.C. Chou's wife, June, and his son, Scott (B.S. '86), as a lasting tribute to his lifetime dedication to the pursuit of scholarly research and foregoing personal gain in favor of always doing the right thing for society.

ROBERT F. CHRISTY PRIZE FOR AN OUTSTANDING DOCTORAL THESIS IN THEORETICAL PHYSICS

This prize is given annually to a student who has produced an outstanding thesis in theoretical physics. Established in 2018, this prize honors the memory of Robert F. Christy, former provost and professor of theoretical physics.

MILTON AND FRANCIS CLAUSER DOCTORAL PRIZE

This prize is given to a Ph.D. candidate* whose thesis is judged by a committee of the Faculty Board to exhibit significant new work, ingenuity, and originality, and to have the greatest potential to open new avenues of human thought and endeavor.

CMS AND IST GRADIENT FOR CHANGE AWARD

The CMS and IST Gradient for Change Awards honor students, postdocs, staff, and faculty in the Caltech community who demonstrate exceptional efforts to make Caltech and/or the broader scientific community a more diverse, equitable, and inclusive environment. The awards recognize and highlight individual contributors or small teams who are considered agents of change, community leaders, and/or allies to historically marginalized group(s) in the information sciences, including computer science, applied mathematics, and beyond.

DONALD COLES PRIZE IN AERONAUTICS

This prize is given to the graduating Ph.D. student in aeronautics whose thesis displays the best design of an experiment or the best design for a piece of experimental equipment.

FRANCE CÓRDOVA GRADUATE STUDENT FUND IN PHYSICS

This fund provides resources for one to three graduate students annually to support research-related expenses. Each awardee shall be recognized as either a Neugebauer, Garmire, or Tombrello Scholar. Preference shall be given to student(s) studying broadly in areas in which professors Gerry Neugebauer, Gordon Garmire, and Thomas

Tombrello made contributions.

JAMES A. CULLEN MEMORIAL FELLOWSHIP FUND

This memorial fund is awarded annually to a graduate student or students who have demonstrated outstanding academic achievement in physics.

DEMETRIADES-TSAFKA-KOKKALIS PRIZE IN BIOTECHNOLOGY OR RELATED FIELDS

This prize, awarded annually, recognizes a Ph.D. candidate for the best thesis, publication, or discovery in biotechnology or related fields at the Institute in the preceding 12 months. This prize is made possible by a gift from Anna Kokkalis Demetriades and Sterge T. Demetriades (Eng. ’58).

DEMETRIADES-TSAFKA-KOKKALIS PRIZE IN ENTREPRENEURSHIP OR RELATED FIELDS

This prize, awarded annually, recognizes the best business plan or proposal, start-up, thesis, publication, discovery, or related efforts by student(s) in entrepreneurship or related fields at the Institute in the preceding 12 months. This prize is made possible by a gift from Anna Kokkalis Demetriades and Sterge T. Demetriades (Eng ’58).

DEMETRIADES-TSAFKA-KOKKALIS PRIZE IN ENVIRONMENTALLY BENIGN RENEWABLE ENERGY SOURCES OR RELATED FIELDS

This prize, awarded annually, recognizes a Ph.D. candidate for the best thesis, publication, discovery, or related efforts in benign renewable energy sources or related fields at the Institute in the preceding 12 months. This prize is made possible by a gift from Anna Kokkalis Demetriades and Sterge T. Demetriades (Eng. ’58).

DEMETRIADES-TSAFKA-KOKKALIS PRIZE IN NANOTECHNOLOGY OR RELATED FIELDS

This prize, awarded annually, recognizes a Ph.D. candidate for the best thesis, publication, or discovery in nanotechnology or related fields at the Institute in the preceding 12 months. This prize is made possible by a gift from Anna Kokkalis Demetriades and Sterge T. Demetriades (Eng. ’58).

DEMETRIADES-TSAFKA-KOKKALIS PRIZE IN SEISMO-ENGINEERING, PREDICTION, AND PROTECTION

This prize, awarded annually, recognizes a Ph.D. candidate for the best thesis, publication, or discovery in seismo-engineering, prediction, and protection at the Institute in the preceding 12 months. This prize is made possible by a gift from Anna Kokkalis Demetriades and Sterge T. Demetriades (Eng. ’58).

EAS NEW HORIZONS DIVERSITY, EQUITY & INCLUSION AWARD

This award recognizes and honors individuals within the EAS community who have actively contributed to the Division's goal to be a diverse, equitable and inclusive engineering community.

CONSTANTIN G. ECONOMOU MEMORIAL PRIZE

This prize is awarded to a chemical engineering graduate student distinguished by outstanding research accomplishments and exemplary attitude while fulfilling candidacy requirements for the Ph.D. degree.

EVERHART DISTINGUISHED GRADUATE STUDENT LECTURE SERIES

This award recognizes graduate students for their exemplary presentation skills and research ability. Awardees participate in the Everhart Lecture Series, a forum that is meant to encourage interdisciplinary interaction among graduate students and faculty, to share ideas about recent research developments.

LAWRENCE L. AND AUDREY W. FERGUSON PRIZE

The Ferguson prize is awarded to the graduating Ph.D. candidate in biology and biological engineering who has produced the outstanding doctoral thesis for the past year.

HENRY FORD II SCHOLAR AWARDS

This award recognizes either the engineering students with the best academic record at the end of the third year of undergraduate study or the engineering students with the best first-year record in the graduate program.

GPS AWARD FOR ACADEMIC EXELLENCE IN RESEARCH

Awarded to a GPS graduate student for outstanding research achievements.

GRADUATE DEANS' AWARD

This award is given to a Ph.D. candidate or candidates who, throughout their graduate study at the Institute, have made great contributions to graduate life and whose qualities of leadership and responsibility have been outstanding.

THE CALTECH Y LUCY GUERNSEY AWARD

This award recognizes graduate and undergraduate students who have provided exceptional service to the Caltech Y and/or the community. Recipients are selected based on their active involvement in Caltech Y service projects, demonstrated leadership in community and volunteer service efforts, and a strong spirit of service.

HANS G. HORNUNG PRIZE

This prize is awarded for the best oral Ph.D. defense presentation by a student advised by aerospace faculty. The decision is made by a committee of students who attend all thesis presentations for the year.

THE HOUSES AND RESIDENCES IDEA AWARD

The Houses and Residences IDEA Award celebrates exceptional individuals who excel in fostering a vibrant and inclusive environment within the Houses and Residences. Their unwavering commitment ensures that each resident feels a deep sense of belonging and support. These leaders drive positive transformation by nurturing inclusive dialogues and instilling a strong sense of community through advocacy. Through their efforts, they create an environment where everyone can flourish in Houses and Residences.

THE IDEA ADVOCATE AWARD

This award is given to individuals who promote the needs and experiences of other students, staff, or faculty to challenge systemic barriers that impede individuals from contributing their skills and talents in the classroom, workplace, or community. Such actions include raising awareness, inspiring action, advocating for an equitable campus climate, and leading efforts to dismantle structural barriers upholding oppression, and discrimination.

THE IDEA ALLYSHIP & ADVOCATE AWARD

This award is given to an individual who promotes the needs and experiences of all members of the Caltech community and challenges systemic barriers that impede members of marginalized identities from contributing their skills and talents at Caltech. Such actions include raising awareness, inspiring action, cultivating an inclusive environment, advocating for an equitable campus climate, and leading efforts to dismantle structural barriers that uphold oppression and discrimination.

THE IDEA OUTREACH & EDUCATION AWARD

This award is given to individuals who teach and inspire interest in inclusion, diversity, equity, and accessibility in the community at large through learning experiences and service. This person takes the initiative to participate in civic engagement through volunteerism, service-learning, and teaching initiatives as a change agent in the community outside of Caltech.

THE INCLUSIVE LABORATORY ENGAGEMENT AWARD

The Inclusive Laboratory Engagement Award celebrates exceptional individuals who excel in their discipline and foster a vibrant and inclusive environment within the graduate student and/or post-doc community, particularly in the laboratory setting. They strive to ensure that each person feels a deep sense of belonging and support. These leaders foster an environment for collaborative research and learning. Through their efforts, they create an environment where everyone can

thrive in their academic and research pursuits.

RICHARD H. JAHNS TEACHING AWARD

The Richard H. Jahns Teaching award is given in recognition of outstanding achievement as a graduate teaching assistant. Dick Jahns got his BS and PhD in Geology from Caltech and from 1946–1960 was faculty here. He was known for giving superb lectures, legendary field trips, and spending long hours mentoring students. Dick said, "the most exciting and rewarding aspect of teaching is seeing already able young people come alive intellectually and seeing the emergence in them of a basic drive, enthusiasm, and enjoyment."

SCOTT RUSSELL JOHNSON PRIZE FOR EXCELLENCE IN GRADUATE STUDIES

This prize is awarded to continuing graduate students for excellence and extraordinary progress in research and/or excellence in teaching in mathematics.

SCOTT RUSSELL JOHNSON PRIZE FOR EXCELLENCE AS A FIRST-YEAR GRADUATE STUDENT

This prize rewards excellence in first-year graduate research in mathematics.

SCOTT RUSSELL JOHNSON GRADUATE DISSERTATION PRIZE IN MATHEMATICS

This prize is awarded for the best graduate dissertation in mathematics.

KALAM PRIZE FOR AEROSPACE ENGINEERING

This prize, made possible by Dr. Abdul Kalam, the 11th president of India and an aerospace engineer, is awarded to a student in the aerospace engineering master's program whose academic performance was exemplary and who shows high potential for future achievements at Caltech.

R.K. KAR AWARD FOR RESEARCH IN PHYSICS

This award is given annually to an outstanding graduate student who is exceptional in their physics studies and research (emphasis on condensed matter physics).

JOHN O. LEDYARD PRIZE FOR GRADUATE RESEARCH IN SOCIAL SCIENCE

The prize rewards the best second-year paper by a graduate student in Social Science or Social Decision Neuroscience. The prize was established by Susan G. Davis in recognition of John O. Ledyard's dedication to developing graduate students as independent researchers and his service to the Division of the Humanities and Social Sciences. The prize is awarded annually by a committee of social science faculty to a sole-authored work and carries a cash award of $1,000.

THE HERBERT NEWBY MCCOY AWARD

This award is given to one or more chemistry doctoral students for outstanding contributions to the science of chemistry.

DR. NAGENDRANATH REDDY BIOLOGICAL SCIENCES THESIS PRIZE

The Reddy prize is awarded to the graduating female Ph.D. candidate in the Division of Biology and Biological Engineering who has produced the outstanding thesis in the biological sciences or bioengineering for the past year.

ELEANOR SEARLE PRIZE IN LAW, POLITICS, AND INSTITUTIONS

The Eleanor Searle Prize was established in 1999 by friends and colleagues to honor Eleanor Searle, who was the Edie and Lew Wasserman Professor of History at Caltech. The prize is awarded to an undergraduate or graduate student whose work in history or social sciences exemplifies Eleanor Searle's interests in the use of power, government, and law.

ERNEST E. SECHLER MEMORIAL AWARD IN AERONAUTICS

This award recognizes an aeronautics student who has made the most significant contribution to the teaching and research efforts of GALCIT (Graduate Aerospace Laboratories of the California Institute of Technology). Preference is given to students working in structural mechanics.

JOHN STAGER STEMPLE MEMORIAL PRIZE IN PHYSICS

This prize is awarded annually to a graduate student in physics for outstanding progress in research as demonstrated by an excellent performance on the oral Ph.D. candidacy exam.

R. BRUCE STEWART PRIZE

This prize is awarded annually to a graduate teaching assistant in physics who demonstrates, in the broadest sense, unusual ability, creativity, and innovation in undergraduate and graduate classroom or laboratory teaching.

THOMAS A. TISCH PRIZE FOR GRADUATE TEACHING IN COMPUTING AND MATHEMATICAL SCIENCES

The Graduate Teaching in CMS Awards were established in 2016 with a gift from Microsoft and then endowed through the generosity of Thomas A. Tisch (BS '61). The prize and honorarium are awarded to a graduate and an undergraduate student for outstanding teaching and course development in computing and mathematical sciences. Awardees are selected by a committee of CMS faculty members.

THREE MINUTE THESIS

Originally conceived by the University of Queensland and jointly sponsored by the Caltech Library and the Graduate Studies Office, the Three Minute Thesis (3MT®) competition challenges Caltech graduate students to explain their research in an engaging and clear three-minute talk intended for a non-specialist audience.

CHARLES WILTS PRIZE

The Charles Wilts Prize is awarded annually for outstanding independent research in electrical engineering leading to a Ph.D degree. This prize was established in 1992 to honor Charles Wilts, a member of the electrical engineering faculty from 1947–1975, who made substantial contributions to the Department of Electrical Engineering.

THE OUTSTANDING MENTEE AWARD

The Outstanding Mentee Award is given to women who demonstrated a sincere desire to succeed as a researcher and is committed to her personal development, open and willing to learn from her mentor and receptive to advice and counsel, worked with her mentor to establish realistic goals and demonstrated a commitment to carrying them out.

CANDACE RYPISI OUTSTANDING MENTOR AWARD

This award is given to individuals who are willing to share knowledge and enhance their mentee's professional and personal development. This person has provided emotional and moral support and encouragement while improving or helping facilitate access to career-related information and exposure to various professional resources. This awardee is someone who actively promotes their mentee's sense of competence, confidence, and belonging.

Note: Prizes and awards may be subject to federal and state income tax.

SPECIAL REGULATIONS FOR GRADUATE OPTIONS

AEROSPACE (AE)

Aims and Scope of the Graduate Program

The Institute offers graduate programs in aerospace leading to the degrees of Master of Science in Aeronautics and Space Engineering, and Doctor of Philosophy in Aeronautics and Space Engineering. The programs are designed to provide intense education in the foundations of the aeronautical and space sciences, with emphasis on research and analytical, computational, and experimental methods. Entering graduate students should have a thorough background in undergraduate mathematics, physics, and engineering science.

In working toward a degree in aerospace, a student may pursue major study in one of the following areas: physics of fluids, physics of solids and mechanics of materials, structural mechanics, space technology, computational solid mechanics, computational and theoretical fluid dynamics, aeronautical engineering and propulsion, biomechanics of fluids and solids, technical fluid mechanics, control of aerospace systems and materials.

While research and course work in the aerospace option at the Institute cover a very broad range of subjects, a choice of one of the above fields allows students to focus their activities while taking advantage of the flexibility offered by the breadth of interests of the Graduate aerospace Laboratories (GALCIT).

In consultation with their adviser, students will design a program of study in one of the above fields, consisting of the fundamental courses described in the regulations for the separate degrees listed below, and of electives selected from the list of aerospace-related courses. This will ensure that the graduating student will be well-qualified for a career in aerospace and related fields.

Examinations, Committees, and Student Responsibilities

To help students achieve satisfactory progress in their academic pursuits, the aerospace faculty provides for the following committee and individual support.

Upon beginning the first year of the aerospace program, each student is assigned a faculty (course) adviser whose research field matches the interests of the student as described in the student's statement of purpose in their admissions application. The first-year adviser will guide the student in choosing a set of courses appropriate to the students' interests while ensuring the first-year academic requirements (see below) are met.

Students wishing to pursue studies leading to the Ph.D. must select and be accepted by a research adviser by the end of the spring term of the first year of residence and are required to pass a qualifying examination in the first term of the second year. Having passed the qualifying examination, the student pursues research under the supervision of the research adviser until they are ready to enter candidacy for the Ph.D. At this point, a four-member Candidacy Examination Committee that includes the student's research adviser is assembled and administers a Candidacy Examination to ensure the student has the appropriate knowledge and tools to successfully complete their chosen research activities. The Candidacy Committee is chaired by a faculty member other than the research adviser. The Candidacy Examination should be administered by the start of the second term of the third year of residence, but in any case, must be successfully completed by the end of that year in order to comply with Institute requirements.

Conferral of the Ph.D. degree is contingent on satisfactorily passing the thesis examination before a committee consisting of four examiners, which may, but does not need to, have the same membership as the Candidacy Committee. Students may find further information concerning special option requirements and the requisite

option forms on the GALCIT website.

AE Master's Degrees

Master's Degree in Aeronautics and Master's Degree in Space Engineering
The master's degree program in aeronautics or space engineering is a one-year program that provides advanced training in the areas of aeronautics or space engineering beyond that covered in a four-year undergraduate program. The program consists of a set of five core courses (see details below). There is no research requirement, nor is a thesis required to obtain the degree. The courses required for the master's degree must be completed in one year.

Admission
Students whose highest qualification is a baccalaureate degree equivalent to that given by the Institute are eligible to seek admission to work toward the master's degree. Students are asked to submit course transcripts and letters of recommendation as well as evidence of English language proficiency as detailed in the graduate application. Submission of GRE exam scores is optional for the 2025 admissions process in aerospace. It should be noted that the graduate program at GALCIT is primarily focused on Ph.D.-level research and so priority in admission is given to those who plan to ultimately perform Ph.D.-level research.

Course Requirements
A program of study consists of courses totaling at least 135 units; of these, at least 81 units must be chosen from one of the following curricular tracks:

Aeronautics track
Two 27-unit course sequences chosen from:

- Fluid mechanics (Ae/APh/CE/ME 101 abc)
- Solid/structural mechanics (Ae/AM/CE/ME 102abc)
- Autonomy and control (Ae103a in first term, Ae 103b in second term, and a third course selected from department list in coordination with first-year adviser), 27 units

Experimental methods (Ae 104abc), 27 units.

Space Engineering track
Two 27-unit course sequences chosen from:

- Fluid mechanics (Ae/APh/CE/ME 101 abc)
- Solid/structural mechanics (Ae/AM/CE/ME 102abc)
- Autonomy and control (Ae103a in first term, Ae 103b in second term, and a third course selected from department list in coordination with first-year adviser), 27 units

Space engineering (Ae 105abc), 27 units

Aerospace students in either the Aeronautics or Space Engineering track are required to enroll in a sequence of mathematics courses totaling 27 units appropriate to the student's chosen track and selected in coordination with their first-year advisers. Examples of appropriate courses include ACM/IDS 104, ACM 100ab, ACM 101ab, etc.

Finally, all first-year students are required to enroll in aerospace Engineering Seminar (3 units Ae 150abc).

A grade of C or higher must be achieved in all the required classes unless they are only offered pass/fail, in which case a pass must be achieved in each class. For both the Aeronautics and Space Engineering master's degrees, the remaining 27 units are elective and are to be chosen from courses at Caltech that support the broader goals of the respective programs, subject to the approval of the student's adviser. Students must have a proposed program of courses approved by their adviser prior to registration for the first term of work toward the degree.

Admission to More Advanced Degrees

Students who successfully complete the requirements for the master's degree and who wish to pursue the more advanced degree of Doctor of Philosophy (Ph.D.) must file a petition to continue work toward the desired degree. All students working for the Ph.D. degree are expected to register for and attend the advanced seminar (Ae 208 abc) for a period of at least two years.

AE Degree of Doctor of Philosophy

Admission

Students with a baccalaureate degree equivalent to that given by the Institute are eligible to seek admission to work toward the degree of doctor of philosophy (Ph.D.) in aeronautics or space engineering. Students are asked to submit course transcripts and letters of recommendation as well as evidence of English language proficiency as detailed in the graduate application. Submission of GRE exam scores is optional for the 2025 admissions process in aerospace.

Course Requirements

The course requirements for the first year of the Ph.D. degree are identical to those of the master's degree. Students admitted to graduate study for the Ph.D. degree must complete in their first year a course of study that would qualify them for the master's degree described above. The student may elect to receive the master's degree at the end of their first year after completion of these courses.

Research Adviser

Students wishing to pursue studies leading to the Ph.D. must select and be accepted by a research adviser preferably by the end of their third quarter but no later than the end of their first year of study and prior to taking the qualifying examination described below.

Qualifying Examination
After the first year of graduate study, the student must pass a qualifying examination. The objective of the qualifying examination is to determine if the student is properly prepared and qualified to pursue problems typical of Ph.D.-level research by demonstrating fundamental understanding of the first year courses in the topic area of the exam. The exam also evaluates effective oral communication of technical material as a skill that is required for professional development.

The exam will cover the following subjects:

1. ***Aeronautics track.***
   Two areas chosen from options a-c below:
   a. Fluid mechanics
   b. Solid/structural mechanics
   c. Autonomy and control
   and a third exam in Mathematics
2. ***Space Engineering track.***
   Two areas chosen from options a-c below:
   a. Fluid mechanics
   b. Solid/structural mechanics
   c. Autonomy and control
   and a third exam in Mathematics

The material covered in these examinations is at the same general level and breadth as covered in the corresponding first-year courses. The examinations are typically offered during one week in the first half of the fall term, in the second year of graduate residence at the Institute. A student is examined orally on all topics. In the event of an unsatisfactory performance, the examining faculty members may permit a repeat examination in the appropriate topics. The repeat examination must be scheduled prior to finals week of the winter term and must be completed before the end of the spring term of the same year.

Graduate Teaching Assignment Duties
GALCIT provides opportunities to students to improve their teaching and communication skills that are valuable in many contexts. Ph.D. students are required to perform a minimum of 18 term hours of Graduate Teaching Assistant (GTA) duties within the aerospace Department during their terms of residence. GTA duties will be assigned after the first year in residence and will be based on courses a student has completed.

Candidacy
To be recommended for candidacy for the Ph.D. in aerospace, the applicant must

- have satisfactorily completed at least 135 units of graduate work equivalent to the above Master of Science program;

- pass, with a grade of C or better, 27 units of graduate-level mathematics courses beyond ACM 95/100, and ACM/IDS 104;
- complete (with a grade of C or better, or Pass if the course is only offered Pass/Fail) at least 45 units of aerospace courses numbered Ae 200 or higher, or Ae/ME 118, Ae/ME 120, EE/Ae 157, Ae 159, Ae/Ge/ME 160 and Ae/CE 165ab, excluding research and seminars;
  and
- complete three units of the advanced seminar Ae 208.

A proposed program conforming to the above regulations must be approved by the student's adviser and the option representative prior to add day of the first term of work toward the degree.

In addition to fulfilling these course requirements, the applicant must pass a candidacy examination in the third year of residence at the Institute. This exam should be administered by the start of the second quarter of the third year of residency. This examination aims at determining whether the student is successful in integrating formal course work into a mature understanding of fundamental engineering concepts, and at demonstrating their professional competence in applying these concepts to the problems being addressed in the course of their Ph.D. research.

Minor

No minor is required for the Ph.D. degree. Students are, however, encouraged to take advanced courses appropriate to their particular interests or pursue a minor in consultation with their adviser.

Foreign Languages

Students are encouraged to discuss with their adviser the desirability of studying foreign languages, but there is no formal foreign language requirement for the Ph.D.

Thesis and Final Examination

Prior to graduation, each candidate is required to give a seminar presenting the results of their thesis research. For final examination and thesis completion, see also the general degree requirements and the section on Examinations, Committees, and Student Responsibilities regarding aerospace. For a description of the Institute requirements for conferral of a Ph.D. see Degree of Doctor of Philosophy.

Subject Minor

A student majoring in a field other than aerospace may, with the approval of the option representative, elect aerospace as a subject minor. A minimum of 54 units in subjects acceptable to the aerospace faculty is required.

Problem and Grievance Resolution within aerospace

Students may pursue several avenues for redress concerning personal and academic problems that may arise during their residency, as described earlier in the catalog. Should a student not wish to discuss the relevant issues with their adviser, the option representative and/or

the director are always available to meet with the student.

Educational Exchange Program with École Polytechnique

An educational exchange program is offered by the aerospace option with École Polytechnique (EP). In this exchange program, students selected for participation from Caltech will enroll for one year at EP. Correspondingly, students selected for the program from EP will enroll for one year at Caltech. To be eligible to participate, aerospace students must have completed one full year of study (for Caltech students this is equivalent to the requirements for the M.S. degree) and agree that they will spend one full year at EP. First year (G1) graduate students enrolled in Caltech's doctoral aerospace program will be apprised of the opportunity to participate in an educational exchange program at the master's level at EP. A maximum of two student(s) will be selected by the aerospace faculty from the pool of students who express interest in this program. Caltech students will follow their first (master's) year at Caltech, and their second year in the second-year master's (M2) program at EP. Caltech students must fulfill the requirements of their first-year program and receive their Caltech M.S. diploma prior to proceeding to EP.

Caltech students must register at Caltech during the year spent at École Polytechnique and enroll in the special topics course Ae 240 – Educational exchange at École Polytechnique. This ensures that they maintain their standing as enrolled graduate students at Caltech. It is implied that classes taken at one institution cannot duplicate classes already taken at the other institution. The expectation is that Caltech students will return to Caltech after completing the EP program and continue with their doctoral studies at Caltech. Caltech students should be prepared to take the qualifying exams in the fall term when they return from EP. Caltech students participating in the Caltech/EP educational exchange program will be considered to be on detached duty from Caltech while at EP. A detached duty agreement will be executed for each student that spells out the terms and requirements for the detached duty.

APPLIED AND COMPUTATIONAL MATHEMATICS (ACM)

Aims and Scope of the Graduate Program

Caltech's Computing & Mathematical Sciences department offers an interdisciplinary program of graduate study in applied and computational mathematics leading to the Ph.D. degree. This program is designed to give students a thorough training in fundamental computational and applied mathematics and to develop their research ability in a specific application field. The training essential for future careers in applied mathematics in academia, national laboratories, or in industry is provided by completion of the requirements for a Ph.D. degree in applied and computational mathematics.

The research areas and interests of the applied and computational mathematics faculty cover a broad spectrum representing the use of ideas from across the mathematical sciences to formulate, analyze, and develop algorithms for mathematical models. As reflected by the faculty research activities, there is a strong emphasis on

computational methods and theoretical analysis for solving challenging problems arising from applications in engineering, the sciences, and the social sciences.

Reflecting the interdisciplinary nature of the program, several different groups, in addition to the applied and computational mathematics faculty, contribute to the teaching and supervision of research. Students in applied and computational mathematics are expected to combine their basic mathematical studies with deep involvement in some field of application. Basic general courses are listed specifically under applied and computational mathematics, and these are to be supplemented, according to the student's interest, from the whole range of Institute courses in engineering, the sciences, and the social sciences.

A regular colloquium provides the opportunity for visitors, faculty, and students to discuss current research. In addition there are numerous other specialized seminars linked to ACM.

Admission

Each new graduate student admitted to work towards the Ph.D. in applied and computational mathematics selects course work in consultation with their advisor based on the student's background and interests. The work of the student during the first year will usually include some independent reading and/or research.

Course Requirements

During their graduate study, all ACM students are required to take a total of 12 graduate courses of 9+ units each, selected in consultation with their advisor. The courses ACM/IDS 104, ACM/EE/IDS 116, IDS/ACM/CS 157, IDS/ACM/CS 158, ACM 190, and CMS 290 will not count toward the Ph.D. requirements. The 12 classes must include no fewer than 3 from the core set (ACM/IDS 101ab, ACM/EE 106ab, CMS/ACM/IDS 107a, CMS/ACM 117, ACM 118, CMS/ACM/EE 122); no fewer than 6 from the the core set together with any other ACM 100+ classes; and no fewer than 9 from the previous sets together with any 100+ level classes in EE/CMS/CS/Math. All classes must be taken for grades. The remaining classes will be selected among all level 100+ classes from any option. Three of the core classes are selected by the student, in consultation with their advisor, as the subject matter considered for the qualifying examination. This written exam is administered shortly before the start of the beginning of the second year of study, typically during the month of September (see below). In addition, CMS 290 is required for all first year ACM graduate students during each term (fall/winter/spring).

ACM Master's Degree

Students are not admitted to work toward the master's degree. The master's degree may be awarded to an ACM student only in exceptional cases at the discretion of the ACM Option Representative. Of the 135 units of graduate work required by Institute regulations, at least 81 units of advanced graduate work should be in applied mathematics.

ACM Degree of Doctor of Philosophy

The Preliminary Examination.
Before the beginning of the second year, all first-year students must take a preliminary examination administered by the faculty. Its purpose is to ensure a solid and broad knowledge in applied and computational mathematics, and in the event of a deficiency, to direct the students to necessary courses and reading.

The Candidacy Examination
To be recommended for candidacy for the Ph.D. degree in applied and computational mathematics, all students must, in addition to meeting the general Institute requirements and passing the preliminary examination, pass a candidacy examination administered by a committee that consists of at least four faculty, is approved by the option representative, and is chaired by an ACM faculty member who is not the student's primary research advisor. The examination will ascertain the student's breadth and depth of preparation for research in the chosen area. The examination must be taken within the first three years of residence.

Advising and Thesis Supervision
Upon passing the preliminary examination, the student is required to choose a thesis supervisor who assumes the major responsibility in supervising the Ph.D. thesis. At the same time, an advising committee consisting of three faculty members is formed to help oversee the advising process. This committee should be formed no later than the third year of graduate study. The student's supervisor is part of this committee, but does not chair the committee. The student is encouraged to meet with the committee members informally for advice or suggestions. Joint supervision between two faculty members is also possible, as is seeking a thesis adviser outside the core applied and computational mathematics option, although in this case it is mandatory that an applied mathematics faculty member be nominated as a co-adviser.

Should a disagreement of any kind occur between the student and their supervisor as regards the timely completion of the thesis, the student is encouraged to direct their concerns to the committee chair. If this is not workable, the student should feel free to consult with the option representative, the executive officer, or an applied and computational mathematics faculty member of the student's choice. If the student's concerns cannot be resolved through consultation with these individuals, the student is encouraged to pursue resolution of their concerns through other channels as outlined in the Student Problem Resolution Process.

Academic progress will be reviewed regularly, including at least once annually by the option representative.

An ability to explain concepts and to verbally present one's work is vital to a successful career in research and/or teaching. To this end, students may be required by their advisor and the option representative to occasionally serve as a teaching assistant.

Final Examination
The final oral examination is held within four weeks after the submission of the thesis. The examination covers the thesis and related areas.

ACM Subject Minor
The group of courses must differ markedly from the major subject of study, and must include 54 units of advanced courses in applied mathematics and must not be simultaneously used for fulfilling a requirement of the second option. The qualifying courses exclude ACM 95/100, although some flexibility is allowed depending upon the option of origin. The student must pass an oral examination whose subject is directly related to the material covered in the qualifying courses. This oral examination will be waived if the student has received a grade of A in every course.

APPLIED MECHANICS (AM)

Aims and Scope of the Graduate Program
Applied mechanics (AM) research and study are offered through the Department of Mechanical and Civil Engineering (MCE). The degrees of Doctor of Philosophy (Ph.D.) and Master of Science (M.S.) are offered. In general, students who intend to work full-time toward the Ph.D. degree as a final degree objective are admitted to the Applied Mechanics Graduate Program. The M.S. degree is typically only awarded to students who pursue the Ph.D. degree in applied mechanics at Caltech and who do not already have an M.S. degree in applied mechanics.

The aim of the graduate program in applied mechanics at Caltech is to prepare students for research and professional practice in an era of rapidly advancing interdisciplinary technology. The program combines individual depth of experience and competence in a particular chosen major specialty, with a strong background in the basic and engineering sciences. It strives to develop professional independence, creativity, leadership, and the capacity for continuing professional and intellectual growth.

AM Preparation for the Graduate Program
Entering graduate students are expected to have a thorough background in undergraduate mathematics, physics, and engineering. While a strong undergraduate program in applied mechanics should provide a suitable preparation, students who have not specialized in applied mechanics as undergraduates may also be admitted for graduate study. For example, an outstanding four-year undergraduate program in mathematics and sciences may provide a suitable background as well. The qualifications of each applicant will be considered individually, and, after being enrolled, the student will arrange their program in consultation with a member of the faculty.

AM Master's Degree

The degree of Master of Science in applied mechanics is only awarded to students who do not already have an M.S. degree in applied mechanics. The degree will be awarded upon request by students who have fulfilled the requirements. Only in exceptional cases is there admission to the M.S. program as the final degree objective.

A minimum of 138 units of courses numbered 100 or above, which meet the required master's program listed below, must be passed with a grade of at least C for completion of the master's degree in applied mechanics. All units must be taken for grades, except for courses offered only on a pass/fail basis. The M.S. degree in applied mechanics is typically completed within the first two years of residency at Caltech.

Each student's program must be approved by the adviser and option representative in mechanical and civil engineering before registering for the course.

Required Master's Program

1. Graduate applied mechanics core (45 units). These units should provide a solid base for the student's engineering interest. The courses should be selected from the Core AM subjects listed under the Degree of Doctor of Philosophy Description and Requirements section.
2. Mathematics, engineering, and research electives, except seminar courses (63 units). Research up to a maximum of 27 units.
3. Free electives (27 units). Any course with a number of 100 or greater, may be selected, except that research units and seminar courses can not be included.
4. Graduate Engineering Seminar, AM/CE/ME 150 abc (3 units).

AM Degree of Doctor of Philosophy

The Ph.D. degree in applied mechanics is focused on research. Study and research programs for the Ph.D. degree are individually planned to fit the interests and background of the student. A comprehensive research project resulting in an original contribution to the field, which is documented by a thesis, is required. Institute requirements for the Ph.D. degree are described in the section on degree requirements. A minimum of three academic years in residence as a graduate student are required by the Institute, and two or more additional years are usually needed for preparation of the thesis.

Advising and Thesis Supervision

An interim adviser is appointed for each student upon admission to a graduate degree in applied mechanics. The interim adviser will serve as the primary mentor until the student finds a research adviser. It is the responsibility of the student to find an academic and research adviser within three terms of graduate residence at Caltech. In consultation with the adviser, the student must form a Ph.D. Thesis Advisory Committee within four terms of graduate residence at Caltech. This committee shall consist of at least three members of the

Caltech professorial faculty, with at least two members from the faculty in mechanical and civil engineering. The committee shall meet as requested by the student. Further, the committee shall meet annually to review progress and to approve the registration of the student beyond the fifth year of graduate residence at Caltech.

The adviser and the Thesis Advisory Committee provide the majority of mentoring to the student. In addition, the Option Representative and other members of the faculty are always available to provide advice and mentoring on any aspect of research, progress toward the Ph.D., future careers, and other aspects of life in graduate school and as a professional scientist.

Admission to Candidacy

To be recommended for candidacy for the Ph.D. degree in applied mechanics, the student must, in addition to meeting the general Institute requirements, do the following:

- Obtain the agreement of a professorial faculty member to serve as the students academic and research adviser before the end of the third term of graduate residence at Caltech. In consultation with the adviser, the student must form a Ph.D. Thesis Advisory Committee before the end of the fourth term. This committee shall consist of at least three members of the Caltech professorial faculty, with at least two members from the faculty in mechanical and civil engineering.
- Pass both subject and research components of the oral candidacy examination before the end of the eighth term of graduate academic residence at Caltech. If the student has chosen a subject minor, an examination on the subject of that program may be included at the request of the discipline offering the subject minor.
- Complete a minimum of 195 units of courses numbered 101 or above, that fulfill the required Ph.D. program listed below. All units must be taken for grades and passed with a grade of at least a C, except for courses offered only on a pass/fail basis. The course work towards the Ph.D. degree in applied mechanics is typically completed within the first three years of residency at Caltech.

The faculty will evaluate the student's research progress, class performance, adviser's input, and oral candidacy exam results to determine whether a student will be admitted to or be able to maintain candidacy for the Ph.D. degree.

Required Ph.D. Program

1. *Applied Mechanics Core Subject* (45 units): Course work in core subjects selected from the list below; pass with a grade of at least C: Ae/APh/CE/ME 101 abc, Ae/AM/CE/ME 102 abc, AM/CE 151, Ae/Ge/ME 160 ab, Ae/CE 165 ab, ME/CE/Ge 174, Ae/AM/MS/ME 213, Ae/AM/CE/ME 214, Ae 220, Ae/CE 221, ME/MS/AM 221, Ae/AM/ME 223, AM/CE/ME 252, ME/Ge/Ae 266

ab.
The student may petition the mechanical and civil engineering option representative to accept alternate subjects or areas. These changes should retain core applied mechanics knowledge, should not be a sub-specialty of one of the listed areas, and should represent sufficient breadth. The approval is not automatic; such petitions are submitted rarely and many have been denied in the past. The petition must be submitted to the option representative and approved before the student registers for the course.

2. *Electives or Minor* (63 units): Additional engineering or science courses with course number 101 or above, except seminar or research courses. ACM 100 can be taken as an elective with the advisor's approval. Pass with a grade of at least C, courses that are approved by the Thesis Advisory Committee. These courses are intended to provide further depth and incorporate breadth. These units can be used to satisfy a minor requirement in another option.
3. *Advanced mathematics or applied mathematics* (27 units): Pass with a grade of at least C, chosen in consultation with adviser from the following list: ACM 101 or higher, CDS 232, Ma 108 or higher, Ph 129. The requirement in mathematics is in addition to the requirements above.
4. *Graduate engineering seminar* (6 units): Six terms of AM/CE/ME 150 abc, within 12 terms or, 3 years, in residence at Caltech.
5. *Research* (54 units): Successfully complete at least 54 units of research and demonstrate satisfactory research progress.

Registration Beyond the Sixth Year of Graduate Residence
The annual approval of the Ph.D. Thesis Advisory Committee is necessary for registration beyond the twenty-fourth academic term of graduate residence at Caltech.

Thesis and Final Examination
The thesis examination will be given after the thesis has been formally completed. This examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in the specialized field of research. The format of the examination can be chosen from the following two options, by the student, in consultation with the students research adviser: (i) a public seminar presented by the candidate, with an open question period, followed by a private examination by the Examining Committee or (ii) a private presentation to the Examining Committee followed by the examination, with a public seminar on another date. The Examining Committee shall consist of a minimum of four voting members, three of whom must be Caltech faculty; two members must be from MCE. The Thesis Defense Committee shall be chaired by a committee member who is an MCE Caltech professorial faculty member and not the student's adviser.

AM Subject Minor
A student majoring in another branch of engineering or another division of the Institute may, with the approval of the faculty in the Department of Mechanical and Civil Engineering and the faculty in the students major field, elect applied mechanics as a subject minor. The program of courses must differ markedly from the major subject of study or research, and must consist of at least 54 units of advanced courses (101 or above) approved by the faculty in mechanical and civil engineering.

APPLIED PHYSICS (APH)

Aims and Scope of the Graduate Program
Applied physics is a broad field of study that lies at the intersection of physics and many other fields of science and engineering. The applied physics option at Caltech is accordingly a highly multidisciplinary program that is designed to train students in a broad spectrum of physics and engineering fields at an advanced level. Moreover, it is our goal to cultivate abilities in our graduates to apply this knowledge throughout their lives so as to make technological and scientific breakthroughs at the edge of current knowledge.

APh Preparation for the Graduate Program
Students admitted for graduate study can enter from a broad range of disciplines, but are expected to have a rigorous background in undergraduate mathematics, physics, and engineering. An outstanding four-year undergraduate program in mathematics and sciences may provide a suitable background as well. The qualifications of each applicant will be considered individually. After enrollment, the student will arrange a course of study and research in consultation with members of the faculty and the applied physics option representative.

APh Description of the Degree of Doctor of Philosophy (Ph.D.)
To receive the doctoral degree in applied physics students must demonstrate the ability to formulate and execute an original program of scientific study. As part of this, a doctoral candidate is expected to develop a deep understanding in a chosen field of specialization; to develop tools with which to assess problems outside one's field of specialization; to develop rigor and strength in the physical sciences for self-education beyond formal training; and to develop skills to become a productive member of the community of scholars. All students wishing to enter the program must complete a series of preparatory courses, followed by an oral candidacy exam in which the student describes their proposed topic of research and is examined on their knowledge of course subject matter. Upon passing the candidacy examination, students work towards completion of a thesis in consultation with their research adviser. The doctoral degree is awarded upon approval of a written thesis by a faculty committee, and successful defense of the thesis in a final oral examination. There is no separate master's program in applied physics. However, with the

approval of the student's adviser and the applied physics option representative, the degree of Master of Science in Applied Physics may be awarded after the fulfillment of the course requirements described below.

APh Advising and Thesis Supervision
An interim adviser is appointed for each student upon admission to the graduate program in applied physics. Typically, this person is the applied physics option representative. In consultation with the interim adviser the student will determine a course schedule and identify a faculty research adviser. This most often occurs within the first six months of graduate residence. The faculty adviser is the student's primary mentor and the student will work in the adviser's research group to formulate and execute a plan of study leading to the thesis. In consultation with their research adviser, the student will also form a Ph.D. Thesis Advisory Committee. This four-member committee should include the student's adviser and at least three members of the Caltech professorial faculty from either the applied physics or physics options. The Thesis Advisory Committee will conduct the qualifying examination and also approve the thesis and conduct the thesis defense. The membership of this committee may change between the time of the qualifying exam and the final defense.

APh Requirements for Candidacy to the Ph.D. Degree
To be recommended for candidacy for the Ph.D. degree in applied physics, a student must demonstrate mastery in the following five areas of pure and applied physics:

- Classical Physics: Mechanics and Electromagnetism
- Quantum Mechanics
- Mathematical Methods
- Statistical Physics and Thermodynamics
- Biophysics, Optical Physics, Hydrodynamics, Plasma Physics, or Solid-State Physics

A. Graduate Coursework toward Candidacy
In partial fulfillment of the "mastery" requirement a student must successfully complete a minimum of 108 units of courses numbered 101 or above from the course schedule. In addition, 4 units of APh 110ab must also be completed. All courses must be passed with a grade of at least a C, except for courses offered only on a pass/fail basis. Students must also complete the degree progress report online upon completion of their courses.

Note: Any given class can only be used for one requirement category.

	Total Units
1. Classical Mechanics and Electromagnetism	**18**

Ph 106 ab or Ph 106 bc Or, with option representative approval, units may be used from: Ph 101, APh/Ph/Ae/MS 153, APh/Ph/MS 152, APh 156 abc, or Ph 136 abc	
2. Quantum Mechanics	**18**
Ph 125 ab or Ph 125 bc or Ch 125 ab or Ch 125 bc Or, with option representative approval, units may be used from: Ph/APh 137 abc, Ph 205 abc, or Ph/CS 219 abc	
3. Mathematical Methods	**18-24**
ACM/IDS 101 ab or Ph 129 ab or Ph 129 abc. One quarter in the sequence may be substituted with APh/MS 141. Or, with option representative approval, units from other Mathematics or Applied Mathematics courses.	
4. Statistical Physics and Thermodynamics	**18**
APh/MS/ME 105 ab or APh/MS/ME 105 bc or Ph 127 ab Or, with option representative approval, units may be used from: Ae/ME 118, Ae/ME/APh 218, Ch/ChE164, Ch/ChE165, Ph 127 c, Ph 135, or Ph 223 ab	
5. Elective Classes	**36**
Select From: Ae/APh/CE/ME 101 abc, APh/EE 109, APh 114 abc, APh/EE 130/131/132, APh 156 abc, APh/Ph 138 ab, APh/Ph/MS 152, APh/Ph/Ae/MS 153, APh/EE 183, APh/EE 190 abc, APh/MS 256, BE/Bi/APh 161, EE/APh 120, EE/APh 123, EE/APh 149, EE/APh 158, EE/APh 180, MS/APh 122, Ph 106 c, Ph 125 c, Ph 127 c, Ph/APh 137 ab, Ph/APh 223 ab, or Ph/APh/EE/BE 118 ab. Or other courses with approval from option representative.	

First year students are also required to take APh 110 ab, a two-term seminar course in which faculty review their research areas and ongoing research work in their group.

	Total Units
Faculty Presentation Seminar for 1st Year Graduate Students	**4**
APh 110 a (2 units)	
APh 110 b (2 units)	

In addition to work in the classroom, students must complete a minimum of 27 units of laboratory or reading research through APh 200.

	Total Units
Applied Physics Research	
APh 200	27

Students entering the program with advanced preparation may choose either to substitute more advanced courses in the topical areas shown or demonstrate competency by successfully passing both the midterm and final examinations. In such cases, students may petition the Applied Physics option representative to accept alternate subjects or areas. These changes should retain core applied physics knowledge, and maintain sufficient breadth. All such petitions must be submitted to the option representative and approved before the student registers for the course.

Coursework towards the Ph.D. degree in Applied Physics is normally completed within the first two years of graduate residency.

B. Candidacy Examination

To fulfill the requirements for candidacy all students must pass an oral examination after completing their coursework. This examination must be taken before the beginning of the student's third year in residence. Students will be expected to deliver a half-hour oral presentation giving a prospectus on their proposed thesis research. Following questions on the research prospectus, a more open-ended set of questions will be posed to the student by the committee members to test general proficiency in the five areas of pure and applied physics listed above. Students who fail the oral examination on their first attempt will be given additional guidelines for further study and an opportunity to retake the examination a second and final time if the committee so recommends. Students who fail the oral examination a second time cannot continue with doctoral studies leading to the Ph.D. Upon recommendation of the examining committee, however, a student may be granted a master's degree. Annual approval of the applied physics option representative is necessary for registration beyond the third year of graduate residence if the student has not completed the candidacy examination.

Students who fulfill the requirements above will be recommended for candidacy to the doctoral program and a master's degree (if applicable) in applied physics.

APh Ph.D. Thesis Requirements

The candidate is to provide a draft copy of the completed thesis to the members of the examining committee (typically the same as the thesis committee) at least two weeks before the final oral examination. The date of the examination and the composition of the examining committee will not be approved by the dean of graduate studies until

the thesis is submitted in completed form, i.e., ready for review by the dean, the members of the thesis committee, and the Graduate Office proofreader. Registration is required for the term in which the thesis defense is taken, but is not normally allowed beyond the last date of the term. For more information, please see the section entitled "Information for Graduate Students" in the *Caltech Catalog*.

APh Ph.D. Final Examination
The candidate shall undergo a final broad oral examination (thesis defense) in the field, to include the subspecialty represented by the thesis and the significance of its findings to the field. This oral examination will be administered at least two weeks after the doctoral thesis has been presented in final form so that the examining committee has sufficient time to review its content. This examination must be taken at least three weeks prior to the date on which the degree will be officially conferred.

APh Registration Beyond the Sixth Year of Graduate Residence
The annual approval of the student's Thesis Advisory Committee is necessary for registration beyond the twenty-fourth academic term of graduate residence at Caltech.

APh Subject Minor
Graduate students majoring in other fields may elect a minor in applied physics. In addition to general Institute requirements, the student must complete, with a grade of C or higher, 81 units of courses in applied physics above the 100 level, excluding APh 200. The minor is also subject to the following conditions:

- Students cannot use courses required by their major option in fulfillment of this requirement.
- Students interested in a minor must receive prior approval from the option representative in applied physics, who will review and approve the proposed course of study.
- It is recommended that this course of study include advanced courses spanning different subfields of applied physics.

ASTROPHYSICS (AY)

Aims and Scope of the Graduate Program
The primary aim of the graduate astrophysics program at Caltech is to prepare students for creative and productive careers in astrophysical research and a variety of other challenging vocations. The astrophysics program emphasizes independent research by graduate students, who are free to pursue study in virtually any area of astrophysics. The opportunity exists to take advantage of the many observational facilities owned and operated by Caltech.

Ay Admission
Incoming students should have a strong background in physics. Although preparation in astronomy is helpful, this is not required for admission to the graduate program. In addition to demonstrating academic readiness, applicants should provide evidence of research readiness.

Ay Master's Degree
While the option does not offer a master's degree program in itself, students who fulfill the general Institute requirements for such a degree, and the specific option requirements (see below), can receive a master's degree. This may be either en route to a final Ph.D. degree if admitted to candidacy, or as a terminal degree if the Ph.D. requirements are not met.

The choice of astronomy and other science elective courses must be approved by the option representative. At least 54 units of the 135 units must be selected from Ay 121–127, with at least 36 units earned with a grade of B- or better. The courses Ph 106, Ph 125, and Ph 129 may be required of those students whose previous training in some of these subjects proves to be insufficient. At least 27 units of advanced courses in fields other than astronomy are required.

Ay Degree of Doctor of Philosophy
The student's proposed overall program of study must be submitted for approval by the option representative during the first year.

Astrophysics Core Program
The following are required of all students for candidacy: Ay 121, Ay 123, Ay 124, Ay 125, Ay 126, and Ay 127. These courses should be taken in the first year. Observational students must also take at least one term of Ay 122. For theory students, Ph 136 a and Ph 136 b are required. Also required for all students are research and reading projects. Credit for this work will be given under Ay 142 and Ay 143. The above courses must be passed with a grade of B– or better.

Electives Program
The first two years of graduate study should include at least four courses (36 units) of additional electives relevant to astrophysics. The electives requirement may be reduced for students who need to take Ph 106, Ph 125 or Ph 129 in order to make up for gaps in preparation at the undergraduate level.

Suggested elective courses include, but are not limited to: Ph 101, Ph 105, Ph/Aph 118 a, Ph 127 b, Ph 135, Ph 136 ab, Ph 236 a, Ph 237. For theory students Ph 136 c and Ph 101 are highly recommended, in addition to other Ph courses; electives in applied mathematics should also be considered. For students in observation and experiment, Ph 136 a and Ph 136 b are strongly recommended, and in any case at least one of the four advanced course electives must be in Ph, while the complement may be from other options such as electrical engineering, applied mechanics, computer science, planetary science (geophysics or geochemistry).

No more than 18 of the elective units may be taken P/F; all others must be passed with a grade of C or better. Seminar courses and research practicum courses do not count as satisfying the requirement for pedagogical elective coursework; however, students are encouraged to take these types of courses during second year. In the third year and above, students are welcome to enroll in additional advanced astronomy and physics courses.

Other Requirements

Each term, the student must be registered for at least 36 academic units, with additional electives such as from PA/PE/HSS allowed on top of the 36.

An ability to explain concepts and to verbally present one's work is vital to a successful career in research and/or teaching. To this end, all graduate students in Astrophysics are required to serve as teaching assistants during their second year, and to make oral presentations as part of the course Ay 141, which must be taken every term during the academic year by all students, beginning in their second year and continuing through graduation.

Graduate students for whom English is a second language may be required to demonstrate fluency in oral and written English at the time of their candidacy exam. The examining committee will arrange for an evaluation if this is deemed necessary.

In the fall of their second year, all students are required to take a general oral qualifying examination. Students will be examined on the substance and status of, as well as their performance on, a research project, which should be started not later than the summer following the first year. They will further be examined on their broad understanding of current topics in, and fundamentals of, astrophysics. Both of these aspects of the examination are intended to evaluate the candidate's aptitude for a research career in astrophysics. In addition, at the discretion of the executive officer, students who have not done well in one, or at most two, areas covered in the Ay 12x course series during their first year will be retested in these areas during the examination. Students must pass all of the aspects of this examination, as judged by the faculty committee conducting it, in order to continue in the Ph.D. program.

Students who do not meet the minimum grade requirements in the Ay 121–127 series, or who do not pass the general qualifying examination described above, will not be able to continue in the Ph.D. program. They may receive a terminal master's degree, provided that they fulfill the requirements for it (see above).

Admission to Candidacy

To be recommended for candidacy for the Ph.D. degree in astrophysics, a student must, in addition to meeting the general Institute requirements:

- pass satisfactorily, or by special examination, the required astrophysics courses (see above);
- pass a general oral qualifying examination (see below);

- complete the physics-based electives course requirement (see above);
- satisfy a teaching requirement (generally two-three terms as a graduate teaching assistant);
- fulfill the language requirement if applicable (see above);
- complete satisfactorily 36 units of research (Ay 142) or reading (Ay143);
- be accepted for thesis research by a member of the faculty.
- pass a thesis candidacy examination (see below).

Students who do not advance to candidacy will not be able to continue in the Ph.D. program, but will receive a terminal master's degree.

Research Advising and Thesis Supervision

By the summer of their first year, students should be spending most of their time on research. During their first two years, students can work with faculty members on one or more projects. By the summer of the second year, at the latest, students should have defined a thesis project and been accepted by a faculty research adviser for that project. (In cases where the thesis involves multiple projects, a second faculty adviser may supervise part of the research, but one must be selected as primary adviser).

An oral candidacy exam dealing with the student's proposed thesis research should be completed before the end of the third year. The date and time of the exam are the responsibility of the student to arrange. The candidacy committee is approved by the option representative in consultation with the student's adviser and informed by a list of suggested members provided by the student. This committee becomes the student's Thesis Advisory Committee (TAC) and will stand until the final oral thesis defense, and be charged with ensuring that satisfactory progress toward the Ph.D. is being made.

If the candidate does not pass the oral candidacy exam, then the candidacy committee may at its discretion offer the candidate a second oral examination. This examination must be successfully completed by the end of the third term of the third year.

After the oral candidacy exam, the adviser and the student together have primary responsibility for the student's progress and career development. To ensure that these remain on course, both student and adviser must submit annual progress reports to the option representative, or in the case of a conflict of interest, to the executive officer or to the division chair. Students should arrange to meet for a "check-in" with the thesis advisory committee members at least once per year. If at any stage the student or the adviser feels that there are serious problems developing, they may consult in confidence with the astrophysics option representative, the executive officer, or the division chair. They may also request a meeting of the committee or seek the advice or help of other faculty members. Students may also consult at any time with the PMA director of student programming or seek confidential advice and help from the Student Wellness Services.

Final Examination (Ph.D. Oral Thesis Defense)
A final draft of the thesis must be submitted to the registrar at least six weeks before the commencement at which the degree is to be conferred. At least two weeks after submission of the thesis, the student will be examined on the scope of the thesis and its relation to current research in astrophysics. The examination will be conducted by a committee selected in the same way as the candidacy committee, and is nominally the thesis advisory committee. The oral thesis defense should occur before the end of the fifth year.

Typical Timeline
Year 1: Ay 121, Ay 123–127; at least two advanced physics courses; reading and independent study. Begin research.

Year 2: General oral qualifying examination in early fall. Fulfill teaching requirement. Complete physics electives; a term of Ay 122 if applicable; optional advanced astronomy courses. Ay 141 each term. Research projects; select thesis and adviser.

Year 3: Complete oral candidacy exam on proposed thesis before end of third term. Submit annual report to option representative. Ay 141. Optional Advanced Courses

Year 4: Submit annual report. Thesis Advisory Committee (TAC) check-in. Ay 141.

Year 5: Submit annual report. Thesis Advisory Committee (TAC) check-in. Ay 141. Complete Ph.D. thesis work and writing before the end of year 5. Final oral thesis defense.

BIOCHEMISTRY AND MOLECULAR BIOPHYSICS (BMB)

Aims and Scope of the Graduate Program
An integrated approach to graduate study in biochemistry and molecular biophysics has been organized primarily by the Divisions of Biology and Biological Engineering (BBE) and Chemistry and Chemical Engineering (CCE). The curriculum is designed to provide a broad background in biochemistry and biophysics of macromolecules and molecular assemblies, in addition to an appropriate depth of knowledge in the field selected for the Ph.D. thesis research.

BMB Admission
The option in Biochemistry and Molecular Biophysics is open to students with undergraduate degrees in biochemistry, biology, chemistry, biophysics, physics, engineering, and related areas. Applicants whose native language is not English may submit results of the TOEFL exam and, after admission, are required to satisfy the English language requirements of the Institute.

BMB Master's Degree
Students are not admitted to work toward the M.S. degree. A terminal M.S. degree may be awarded only in special circumstances. In addition to meeting Institute requirements, a student must have formed a committee of four Caltech faculty, typically the Ph.D. candidacy committee, who must approve the request to obtain a M.S.

in consultation with the Option Representative, typically conferred after the end of the second year of residence.

BMB Degree of Doctor of Philosophy

The option representative will counsel and oversee the student's progress upon admission to the graduate program. During the first year of graduate study, students are required to participate in the BMB 202 seminar course and BMB 174. Additionally, as noted below, the option offers a series of courses that will expose the student to contemporary issues in biochemistry and molecular biophysics, and to the tools and methods that are essential for research in this area. Research advisers are normally selected at the end of spring quarter of the first year. Students are required to take five additional advanced courses of nine or more units for grades that are appropriate for their research interests (as determined by the option representative).

Teaching

All students are to serve as teaching assistants for two quarters with the first in the first year of residence and the second by the end of the fourth year. In addition to serving an educational purpose, funds for the TA assignments are a component of the stipend. Outside factors, such as previous TA positions prior to starting the Ph.D. program, may be considered as satisfying the requirement upon approval by the option representative.

Laboratory Rotations

In consultation with the Option Representative and individual professors, students will choose three laboratories to do one term research projects during their first year of residence. These laboratory rotations are designed to provide students with an introduction to different areas of biochemistry and molecular biophysics along with identifying a lab for thesis research. It is possible to waive the third rotation with permission given by petitioning the Option Representative.

Admission to Candidacy

By the end of the sixth term of residency, the student will take an oral examination to assess mastery of the field of biochemistry and to evaluate research progress. As part of this examination, each student will submit a written research report summarizing the progress in their research, and an original research proposal in a field outside the student's chosen field of research. A candidacy examination committee of four to five faculty (including the advisor) will be assembled by the student in consultation with their advisor and approved by the Option Representative. The chair of the committee should be identified at the time the committee is chosen and must be a member of the BMB option who is not the thesis advisor. In addition to satisfactory completion of the Candidacy exam, admission to Candidacy requires satisfactory completion of BMB 174 and five additional advanced courses of nine or more units (numbered 100 or above).

Thesis Committee and Annual Progress Meetings
Upon admission to candidacy, the candidacy examination committee will become the thesis advisory committee. Students are required to meet annually with their thesis advisory committee to evaluate research progress. This committee will also serve as the Ph.D. thesis examination committee. A fifth member may be added at this time.

Thesis and Final Examination
Thesis research will be carried out under the direction of one or more faculty members in the BMB option. The thesis defense will consist of a public thesis seminar, followed by a closed examination by the Ph.D. thesis committee.

BIOENGINEERING (BE)

Aims and Scope of the Graduate Program
Bioengineering research at Caltech focuses on the application of engineering principles to the design, analysis, construction, and manipulation of biological systems, and on the discovery and application of new engineering principles inspired by the properties of biological systems. Areas of research emphasis include: biodevices, bioimaging, bioinspired design, biomechanics, biomedical engineering, cell and tissue engineering, molecular programming, synthetic biology, and systems biology. The goal of the doctoral program is to prepare students to become leading scientists and engineers in academia and industry. The graduate program aims to educate students to be highly competent in their chosen area of research, but also provide them with a broad knowledge foundation in bioengineering. By graduation, students are expected to have a working knowledge of bioengineering in general and an in-depth knowledge of their chosen area, have independently planned and conducted research experiments in their chosen area, and successfully defended their thesis work in an open forum.

BE Master's Degree
Students are not admitted to work toward the M.S. degree. In special circumstances, the M.S. degree may be awarded, provided Institute requirements are met.

BE Degree of Doctor of Philosophy
In addition to satisfying the general Institute requirements, candidates for a Ph.D. in bioengineering at Caltech must satisfy the following requirements:

Course Requirements
Coursework requirements provide maximum flexibility in building on undergraduate training and complementing the research activities of each student. To assist in the selection of a research area, to foster interactions within the entering class, and to discuss ethical guidelines for scientific research, students participate in three required discussion courses in their first year: current research topics in Caltech bioengineering labs (BE 267, first term); Reading the

Bioengineering Literature (BE 201, second term); Responsible Conduct of Research (Bi 252, first term). Graduate students must take BE 201 again in their second year.

In addition to the required courses, students must take at least six electives (one-quarter courses totaling at least 54 units; grade of B or higher in each course) selected in consultation with the student's adviser and the option representative. Students must complete Bi/CNS/NB 195 and BE/Bi 103 a, unless the option representative deems the student's past course work to have covered the topics of those courses and waives the requirement. If a grade of B or better is earned, these two courses count toward the six electives. Waived courses do not count toward the requirement of six electives. To maximize the opportunity for research during the early stages of the graduate career, coursework may be spread over the first and second years. Electives are listed below. Other courses may count as electives at the discretion of the option representative.

Bioimaging and biomedical devices electives: AM/CE 151, APh/EE 109, APh/EE 130, APh/EE 132, BE/EE/MedE 189 ab, Bi/BE 177, Bi/BE 227, APh/EE 131, EE/MedE 185, EE/MedE 187, Ph 106 abc, Ph/APh/EE/BE 118 ab.

Biomechanics and bioinspired design electives: Ae/APh/CE/ME 101 abc, Ae/AM/CE/ME 102 abc, Ae/BE 242, ChE 103 abc, ChE/Ch/Ms 113, ChE 151 ab, ChE/Ch 164, ChE 174, MedE/BE/Ae 243, Ph 127 abc.

Synthetic biology, systems biology, molecular programming, and cell and tissue engineering electives: BE 150, BE 153, BE 159, BE/Bi/APh 161, Bi 117, Bi 145 ab, BE/ChE 163, BE/CS/CNS/Bi 191ab, ChE/Ch/BE 130.

Biology electives: BE 150, Ch/Bi 110 ab, Ch/Bi 111, Bi 114, Bi 115, Bi 117,Bi/BE 119, Bi 122, Bi/BE 129, Bi 145 ab, BE 153, BE 159, BE/Bi/APh 161, NB/Bi/CNS 150.

Math electives: ACM 100 ab, ACM/EE/IDS 116, ACM/EE 118, ChE 105, CDS 110.

Research

The flexibility of the coursework requirements enables research to be the primary activity from the very first term in residence. Students are encouraged to do two or more research rotations during the first year to sample research activities in multiple labs before selecting a Ph.D. adviser. Rotations are arranged by contacting individual faculty.

Adviser Selection

Each student must select a Ph.D. adviser by the end of the spring term of the first academic year. Advisers may be any Caltech faculty member working in an area related to bioengineering.

First Year Conversation
Before the end of the spring term of the first year in residence, each student meets with a faculty committee for a discussion of first-year progress and second-year plans. The committee must be composed of three faculty, plus the Ph.D. adviser(s), including a minimum of two bioengineering faculty. The student will give a brief presentation on research progress and future plans, as well as discuss fundamentals related to the research area.

Teaching
Each student is to serve as a teaching assistant for one quarter of their residence.

Admission to Candidacy
By the end of the spring term of the second year in residence, each student must complete the coursework requirement, prepare a candidacy report, and pass an oral candidacy exam. The report should be brief, describing research progress to date and outlining plans for the remaining doctoral research. The candidacy report should be submitted to the committee members one week before the oral exam. The committee must be composed of three faculty, plus the adviser(s), including a minimum of two bioengineering faculty. The oral candidacy exam will include presentation of research progress, presentation of a proposed outline for the thesis, and questioning on fundamentals related to the research area. Students who complete the coursework requirement, prepare a candidacy report, and pass the oral candidacy exam will be recommended for candidacy. Students who are not admitted to candidacy by the end of the second year in residence will not be permitted to register in subsequent terms except with special permission from the option representative.

Thesis Advisory Committee Meetings
Following admission to candidacy, the doctoral student will select a Thesis Advisory Committee (TAC). The committee must be composed of three faculty, plus the adviser(s), including a minimum of two bioengineering faculty. This committee should meet at least once each year for the remainder of the student's time at Caltech.

Thesis Examination
A final oral examination will be given after the thesis has been formally completed. The exam will consist of a public research presentation followed by a private defense with an exam committee. The committee must be composed of three faculty, plus the adviser(s), including a minimum of two Bioengineering faculty. The thesis examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in their specialized field of research.

BE Subject Minor
A student may, with the approval of the bioengineering graduate option representative, elect a subject minor in bioengineering. Such a program shall consist of 45 units of upper division course work in bioengineering, with each course passed with a grade of C or better. Courses used to satisfy course requirements in the student's major option may not be used to satisfy the minor requirements. Approval of each program must be obtained from the bioengineering graduate option representative.

BIOLOGY (BI)

Aims and Scope of the Graduate Program
Graduate students in biology come with very diverse undergraduate preparation—majors in physics, chemistry, mathematics, or psychology, as well as in biology and its various branches. The aims of the graduate program are to provide, for each student, individual depth of experience and competence in a particular chosen major specialty; perception of the nature and logic of biology as a whole; sufficient strength in basic science to allow continued self-education after formal training has been completed and thus to keep in the forefront of changing fields; and the motivation to serve their field productively through a long career.

In accordance with these aims, the graduate study program in biology includes the following parts: (a) the major program, which is to provide the student with early and intense original research experience in a self-selected subject of biology, supplemented with advanced course work and independent study in this subject; and (b) a program of course work designed to provide well-rounded and integrated training in biology and the appropriate basic sciences, which is adjusted to special interests and needs. An individual program will be recommended to each student in a meeting with the student's advisory committee (see below). The Division of Biology and Biological Engineering does not encourage applications from students who have pursued undergraduate study in biology at the Institute, because the broader perspective to be gained from graduate study in a different setting is considered to be essential for the full development of each student's potential. Exceptions to this policy may be considered by the faculty of the division if there are circumstances that indicate that it would be in the best interests of a student to pursue graduate study at the Institute.

Bi Admission
Applicants are expected to meet the following minimal requirements: mathematics through calculus, general physics, organic chemistry, physical chemistry (or the equivalent), and elementary biology. Students with deficient preparation in one or more of these categories may be admitted but required to remedy their deficiencies in the first years of graduate training, with no graduate credit being granted for such remedial study.

Bi Master's Degree

The Biology option does not admit students for work toward the M.S. degree. In special circumstances the M.S. degree may be awarded, provided Institute requirements are met. In general, the degree is not conferred until the end of the second year of residence. The degree does not designate any of the disciplines of the division, but is an M.S. in Biology. The 135 units required by the Institute must include Bi 252 and any two courses from the series Bi 250 abcd.

Bi Degree of Doctor of Philosophy

Major Subjects of Specialization

A student may pursue major work leading to the doctoral degree in any of the following subjects: biophysics, cellular biology, computational biology, developmental biology, genetics, immunology, microbiology, molecular biology and biochemistry, and systems biology. At graduation, a student may choose whether the degree is to be awarded in biology or in the selected major subject. Students who choose to work in neurobiology may also qualify for a Ph.D. in Biology but are encouraged to enroll in the Neurobiology option.

Initial Advisory Meeting

At the start of the first year of study, incoming students meet with the option representative or faculty member(s) specified by the option representative. The purpose of this meeting is to assist the student in organizing laboratory rotations, and to discuss what additional course work is desirable in light of the student's past record.

Rotations

The major initial responsibility of each student is to explore the various research possibilities available at Caltech before settling into a laboratory for their thesis research. Students are free to rotate in any laboratory at Caltech, not just those in the Division of Biology and Biological Engineering. First-year students should carry out a minimum of two laboratory rotations; three rotations are recommended. It is generally expected that rotations will last a full academic quarter; however, exceptions can be granted with the advance permission of the professor. Choice of laboratory should be made by the end of June of the first year except in extraordinary circumstances. Any exception should be discussed with the option representative.

Formal Classes

During the first year of graduate studies, students are required to take Responsible Conduct of Research (Bi 252) and at least two courses from the series Bi 250 abcd that covers the breadth of fields represented in biology at Caltech. During each year that they are matriculated in the Ph.D. program, students are required to take Bi 251 abc (Biolunch). Students will be required to present their thesis research in Biolunch during their second and fourth years of study. In addition to these fixed requirements, during their time at Caltech students must take three additional 100-series or 200-series courses (9 or more units each; grade of B or higher in each course), at least

one of which must focus on mathematical or statistical methods relevant to biology. Each of these classes must be taken for a letter grade if offered. If a letter grade is not offered then pass/fail is acceptable.

Teaching
All students are required to serve as teaching assistants for two quarters while they are in residence. Teaching is optional first year.

Admission to Candidacy
During winter quarter of the second year, a student is to set up a thesis proposal examining committee and prepare a proposal focused on the research project that they expect to pursue for their thesis research. The proposal is defended by the student in an oral presentation in front of the thesis proposal examining committee by the end of June. (Although it is anticipated that this exam will be completed by June of the second year, it can be delayed until August of the third year if the option representative agrees.) The examining committee comprises four faculty members, at least three of whom should hold full or joint professorial appointments in the Division of Biology and Biological Engineering. One of the members of the committee is appointed as chair. The chair of the thesis examining committee must be a Caltech faculty member other than the student's adviser. The adviser can, but need not be, a member of the examining committee. The members of the thesis proposal examining committee must certify passage of this exam. In the event that there is inadequate evidence of the capacity to do research, the student may be allowed to petition to re-take the oral exam at a later time. However, in cases where the committee deems it unlikely that the student will be able to pass a subsequent attempt, the student may be advised to leave the program. In any event, a student cannot remain in the program beyond August of the third year without having successfully completed the requirements for admission to candidacy, except in extraordinary circumstances and with the approval of the option representative and the dean of graduate studies.

Thesis Advisory Committee Meetings
Once a student has been formally admitted to candidacy, they are to pick a Thesis Advisory Committee (TAC). This committee is often the same as the thesis proposal exam committee, but that need not be the case. The thesis adviser must be a member of the TAC. The TAC typically has four members. At least three must be professorial faculty who hold a full or joint appointment in the Division of Biology and Biological Engineering. It is expected that students who have been admitted to candidacy will meet with the TAC once a year for the remainder of their time at Caltech. Students who fail to meet with their TAC in any one year may be deemed to not be maintaining satisfactory progress toward the Ph.D. degree and will be prevented from registering for the subsequent academic year.

Maintaining Satisfactory Progress
It is the policy of the Biology option that a graduate student who is making satisfactory progress toward a Ph.D. degree can expect to continue as a registered student with full financial support. To be deemed as making satisfactory progress, a student is expected to fulfill the expectations listed below. In the event that satisfactory progress is not being made, a student can petition to receive the M.S. degree, for which they must have successfully completed one full year of graduate study. Requirements for satisfactory progress include:

- Completion of the first-year course requirements during the first year.
- Joining a laboratory in which a student will perform thesis research before the end of the first year in residence.
- Passing the qualifying examination and completing admission to candidacy before the start of the fourth year in residence.
- Holding a Thesis Advisory Committee meeting in each subsequent year of studies, and having the thesis committee verify that satisfactory progress is being made.
- Serving as a teaching assistant for two quarters during their time as a Ph.D. student.
- Completing Ph.D. studies by the end of the sixth year.

In the event that the student, option representative, and adviser are in agreement, it is possible to make exceptions to the above guidelines and remain in good standing. Extension of thesis work beyond twenty-four terms requires that the student petition the dean of graduate studies for permission to register. Extensions beyond the seventh year will be allowed only in unusual circumstances. Once a student has passed admission to candidacy, the responsibility for assessing satisfactory progress lies largely with the student's Thesis Advisory Committee. If a majority of the committee deems that a student is not making satisfactory progress, the student is at risk of being removed from the program at any time at the discretion of the option representative.

Examination Committee
Requirements for the Ph.D. thesis and examination are determined by the Ph.D. examination committee that is appointed by the dean of graduate studies for each degree candidate. This committee is usually the same as the Thesis Advisory Committee, but this need not be the case. The composition of the committee must be approved by the option representative. The committee usually has four members. At least three must be professorial faculty who hold a full or joint appointment in the Division of Biology and Biological Engineering.

Thesis and Final Examination
The thesis and associated publications are expected to demonstrate that the student has learned how to conceive, plan, and execute experimental and/or theoretical work that reveals new biological information. In addition, it must reveal a deep, broad, and rigorous understanding of the area of research to which the thesis is relevant.

Two weeks after copies of the thesis are provided to the examining committee, division chair, and option representative, the candidate collects the copies and comments for correction. At this time, the date for the final examination is set at the discretion of the thesis advisor and the division chair. The final oral examination covers principally the work of the thesis, and according to Institute regulations must be held at least two weeks before the degree is conferred. A digital copy of the thesis is required for the Institute Library, including both PDF and original source files. Both should be deposited into CaltechTHESIS.

Caltech-Kaiser Permanente School of Medicine MD/PhD Program
There is a dual-degree program between Caltech and the Kaiser Permanente Bernard J. Tyson School of Medicine (KPSOM) for the granting of the M.D./Ph.D. degree. Students receive their medical training at KPSOM, and perform their Ph.D. work with any member of the Caltech faculty.

Admission to this dual-degree program is made through the KPSOM M.D./Ph.D. process. The M.D. degree is awarded by KPSOM, and the Ph.D. is awarded by Caltech.

The dual-degree program is directed by Dr. Brian Roehmholdt at KPSOM and Professor John Allman at Caltech. For more information, see https://medschool.kp.org/admissions/md-phd-program.

Caltech-UCLA Medical Scientist Training Program (MSTP)
A joint program between Caltech and the UCLA Medical School has been established for the granting of the M.D./Ph.D. degree. Students do their preclinical and clinical work at UCLA, and their Ph.D. work with any member of the Caltech faculty, including the biology, chemistry, and engineering and applied science divisions.

Admission to this joint program is made through the usual UCLA MSTP process, checking a box indicating interest in the Caltech option. Students will be accepted into the joint program, funds permitting. The M.D. degree would be from UCLA and the Ph.D. would be awarded by Caltech.

The current Directors of the UCLA MSTP are Dr. Olujimi Ajijola and Dr. David Dawson, and Caltech Professor Mitch Guttman is the Associate Director. For more information, see mstp.healthsciences.ucla.edu.

Caltech-USC MD/PhD Program
A joint program between Caltech and the USC (Keck) Medical School has been established for the granting of the M.D./Ph.D. degree. Students do their preclinical and clinical work at USC, and their Ph.D. work with any member of the Caltech faculty.

Admission to this joint program is made through the usual USC process, checking a box indicating interest in the Caltech option. Students will be accepted into the joint program, funds permitting. The M.D. degree would be from USC and the Ph.D. would be awarded by Caltech.

The current Director of the USC M.D./Ph.D. program is Dr. Brian Lee. The Director for Caltech is Professor Mitch Guttman. For more information, see keck.usc.edu/md-phd-program.

Bi Subject Minor

A student majoring in any non-biology option of the Institute may, with the approval of the Division of Biology and Biological Engineering, elect a subject minor in any of the subjects listed above under major subjects of specialization. Requirements for such a minor are determined by the faculty committee designated for each subject. A minor program in Biology is also available to students of other divisions. Such a program shall consist of 45 units of upper division course work in the Division of Biology and Biological Engineering, with each course passed with a grade of C or better. Approval of each program must be obtained from the Biology graduate option representative. A student majoring in another division who elects a subject minor in Biology may, if desired, arrange to have the minor designated as Biology, rather than with the name of the specific minor subject.

CHEMICAL ENGINEERING (CHE)

Aims and Scope of the Graduate Programs

The objective of graduate work in chemical engineering is to produce individuals who are exceptionally well trained to apply mathematics, the physical, chemical & biological sciences, and engineering to the understanding of systems involving chemical reactions, transport phenomena, and materials/energy transformations, and to the development of new processes and materials. The program also strives to develop in each student self-reliance, creativity, professional ethics, and an appreciation of the societal impact of chemical engineering and the importance of continuing intellectual growth.

ChE Admission

It is expected that each applicant for graduate study in chemical engineering will have studied mathematics, physics, chemistry, biology, and chemical engineering to the extent that these subjects are covered in the required undergraduate courses at Caltech. In case the applicant's training is not equivalent, admission may be granted but the option may prescribe additional work in these subjects before recommending them as a candidate for a degree.

ChE Master's Degree

Although there is no formal M.S. program in ChE, Ph.D. program students may apply for an M.S. degree.

Course Requirements
At least 135 units of coursework must be completed to satisfy the Institute requirements. These units must include ChE 151ab, ChE 152, ChE/Ch 165, 18 additional units of advanced courses in chemical engineering, 45 units of science or engineering electives. All units must be taken for grades, except for courses offered only on a pass/fail basis. A student must maintain a GPA of ≥ 2.0 to qualify for an M.S. degree. Finally, the M.S. requirements include at least 27 units of research, ChE 280, which represents two terms of research under the supervision of a Caltech faculty member.

Research Report
At least three weeks before the degree is to be conferred, a research report on the work performed under ChE 280 must be submitted to and approved by both the student's adviser and the ChE option representative.

ChE Degree of Doctor of Philosophy

1. Coursework

- *Initial Consultation:* Upon arrival at Caltech, the ChE Ph.D. students will meet with the ChE option representative to discuss the program, adviser selection, and expectations for the first and second terms. During these two terms, students are expected to take a normal load of three courses per term plus 9 units of research (ChE 280) to cover the rotation (see below) and 1 unit of the ChE Seminar Course (ChE 290abc). In most years, the courses during the first term include one each in advanced Reaction Engineering (ChE 152) and Thermodynamics (ChE 165), and a third course in an area of need or an area that lines up with the research interests of the student. The courses during the second term include one each in advanced Transport (ChE 151a) and Statistical Thermodynamics (ChE 164) and a third course as above. The third course taken during the first and second terms must be at least 9 units and graded. The entire first year of study will also be discussed.
- *Course Requirements:* During the first year, Ph.D. students are required to take the five core courses: ChE 151ab, ChE 152, ChE 164, ChE 165, plus three units of the ChE Seminar Course (ChE 290abc) and one additional ChE course from the following list: ChE 112, 113, 115, Ch/ChE 140ab, 147, 148, 155, ESE/ChE 158, 159, BE/ChE 163, 174, 188. All units must be taken for grades, except for courses offered only on a pass/fail basis, and a minimum grade of B- is required in each one. There is also a minimum GPA requirement of 2.5 each term for all courses taken. Failure to meet the minimum GPA requirement in any term, or failure to meet the B- grade requirement for more than one core course, is cause for termination. Exceptions will be considered if petitioned by the research adviser. The petition should be filed soon after completion of the final ChE core class. The petition will be evaluated by the ChE faculty and it must include a plan to

correct the deficiency.

- *Subject Minor or External Coursework:* Each student is required to complete either a subject minor or a general program of courses outside chemical engineering. The general program of courses consists of at least 54 units. A maximum of 27 units from the following list of doubly-listed courses can be used by graduate students as part of the 54-unit requirement: ChE/ESE/ME/MS 111, ESE/ChE 158; Ch/ChE 140ab, 147, ChE/Ch 148, 155, BE/ChE 163, ESE/Ge/Ch 171. A course in the ACM 100ab sequence will be credited 9 units instead of the nominal 12 units as listed in the catalog. Courses offered by options in the Division of Humanities and Social Sciences are explicitly excluded from the general program. The requirements for a subject minor in other options may be found in the current *Caltech Catalog* . The general program of courses must be submitted and approved by the ChE option representative during the first year residence. All courses chosen must be at the graduate level (most 100- or 200- level courses) and should constitute an integrated program of study rather than a randomly chosen collection of courses outside chemical engineering. All units must be taken for grades, except for courses offered only on a pass/fail basis. A grade of C or better is required in any of these courses to remain qualified for the Ph.D. program.

2. Research Adviser

The choice of a research adviser is perhaps the most important decision a graduate student makes during the first year of graduate study. This decision must be made before the end of the second term of the first year, and so it is reasonable to devote significant thought and effort to this task before then.

At the beginning of the fall quarter, all faculty will present overviews of their research program. All first-year students must attend all sessions. Following these presentations, students are expected to meet individually with at least two faculty members to discuss proposed research projects and the possibility of doing a rotation in that faculty member's group during the first or second terms. All students must formally join a group by the end of the second term.

3. Rotations

Rotations serve to acquaint the student with a group's research area and style. Two quarter-long rotations are required. During a rotation, the student must participate in research activities in the chosen group for at least nine hours per week under the tutelage of a faculty or senior group member. At the end of a rotation, the student must produce a research report and give a group presentation. The report, signed by the rotation adviser, is forward to the ChE option representative. If the student and the faculty member decide that the "match" of research interests and personalities is good, the student may remain the same group for a second rotation, effectively joining the group. Otherwise, the student should proceed to do a second rotation in another group with the same requirements as above.

4. Candidacy Exam

All students are required to pass the candidacy examination, ideally before the end of the second term of the second year. This oral exam is administered by a Candidacy Committee and consists of two parts:

- A presentation by the student based on the contents of a research progress report.
- Background questions part broadly related to the research problem presented.

The research progress report must be submitted to the Candidacy Committee members and the ChE option representative at least three weeks before the oral exam date. The report should expound on the research pursued by the student and is expected to exhibit originality and a professional quality of exposition. It should outline the research problem, the proposed approach, the expected contributions in the general problem area, preliminary results, and the progress of the student at the time of writing. It should also provide clear evidence of the student's understanding of the research topic, the underlying science and technology related to that research, and the student's mastering of the relevant techniques and methodology necessary to pursue the proposed research.

The Candidacy Committee consists of four members, with a minimum of two chemical engineering professional faculty. The chair of the committee is a chemical engineering professional faculty member distinct from the adviser. Emeritus faculty, research faculty, JPL staff and external scholars may serve on the committee, with approval of the option representative and the dean of graduate studies in advance of the examination. Any changes to your thesis examination committee or examination after approval must be submitted to your option manager. The choice of the oral exam committee will be made by the student and their research adviser and must be approved by the ChE option representative. It is the responsibility of the student to obtain approval from each proposed committee member for the date and time of the oral exam. The list of the recommended committee members must be submitted to the option representative for approval at least three weeks before the oral exam date.

The second component of the oral exam consists of chemical engineering background questions relating broadly to the student's research topic. The chairperson of the Candidacy Committee shall be responsible for ensuring that the questions are at an appropriate level, consistent with that of undergraduates at Caltech. For example, if the Ph.D. focus is on heterogeneous catalysis, the student must be able to answer questions on basics such as: surface reaction mechanisms, diffusion/reaction in porous media, and multi-component gas-phase transport, etc. Similar considerations apply to Ph.D. projects related to fluid mechanics, thermodynamics, biology, physics, chemistry, etc. The advanced courses taken during the first year should help you prepare well for this part of the exam. Serious gaps in the understanding of classical chemical engineering concepts,

approaches, and methodologies applicable to your research may lead to failing the exam even if research progress is deemed adequate. Furthermore, for interdisciplinary projects going beyond classical chemical engineering, the student will be expected to demonstrate good understanding of the fundamentals in other areas directly relevant to their project.

The candidacy exam may have three outcomes: Pass, Deferred Decision, or Fail. Passing the candidacy exam, along with successful completion of all coursework admits the student to candidacy for the Degree of Doctor of Philosophy. Failing the candidacy exam terminates the student's Ph.D. program at Caltech. When course requirements are met, the student may be awarded an M.S. degree at the recommendation of the Candidacy Committee. In the case of a Deferred Decision, the committee chair will put in writing what is required and the time frame to meet those requirements. Under no circumstances is this time to exceed one term. In any case, a Pass or Fail decision must be reached at the latest by September 1 of the second year in residence. This is a hard deadline for both the student and the committee. If there is no communication to the ChE option representative about this decision, a Fail decision will be entered automatically.

5. Thesis Review Committee

After the student passes the candidacy exam, the Candidacy Committee becomes the "de-facto" Thesis Review Committee, which will be responsible for reviewing the student's progress. The committee must be convened (at least the research adviser and one committee member) during the third year of residency, and every year thereafter to review progress, suggest improvements in research, or resolve any issues that could potentially delay graduation beyond the fifth year of residency. It is the responsibility of the student to organize the annual meetings of the Thesis Review Committee during each academic year. Students will be unable to register for Fall term if they have not met with their Thesis Review Committee during the current academic year. Registration *beyond the fourth year* is subject to written approval by the Thesis Review Committee and the ChE option representative. To expedite the review for registration beyond the fourth year, the student should submit a two- or three-page concise outline of progress and of proposed future research to each member of their committee before the annual review meeting.

6. Final Thesis and Oral Defense

As a final step in the Ph.D. program, the student is required to submit a satisfactory thesis, present a ChE seminar (open to the general public), and pass a final oral examination.

Procedures for Seminar, Exam, and Committee Selection: At least three weeks prior to the exam date, the ChE option manager must be given the title of the seminar, date, time and location. Both the seminar and exam should be scheduled on the same day, with the exam immediately following the seminar. The committee members will be determined by the student and their research adviser, and must be

approved by the ChE option representative and the dean of graduate studies. The examining committee consists of four members, with a minimum of two chemical engineering professorial faculty. The chair of the committee is a chemical engineering professorial faculty member distinct from the adviser. Emeritus faculty, research faculty, JPL staff and external scholars may serve on the committee, with approval of the option representative and the dean of graduate studies in advance of the examination. Any changes to your thesis examination committee or examination after approval must be submitted to your option manager.

7. Graduate Teaching Assignment (GTA) Duties
All Ph.D. students are required to perform a minimum of 24 term-hours of GTA duties within the ChE Department during their studies. The GTA duties will normally be assigned after the first year in residence. Most students find the teaching assistantship a valuable experience for their future careers. Teaching assistantships outside ChE are permitted but the hours do not count toward the 24-hour TA requirement.

Additional Information
Additional information about graduate study requirements and procedures is provided in the chemical engineering graduate studies guide, distributed annually to first-year chemical engineering graduate students.

CHEMISTRY (CH)

Aims and Scope of the Graduate Program
The Caltech chemistry option offers a program of graduate study leading to the Ph.D. degree, with the goal of preparing students for a lifetime of independent research and scientific leadership in the chemical sciences, through careers in academia, industry, or government. Modern chemistry strives to achieve a molecular-level understanding of the natural world and thus forms the basis of modern science, including biology, medicine, materials, nanotechnology, energy and environmental sustainability. The program of study is flexible and highly interdisciplinary, encompassing organic chemistry, inorganic chemistry, chemical biology, biochemistry and biophysics, chemical physics, and theoretical chemistry.

The graduate program in chemistry emphasizes research. This emphasis reflects the Institute's traditional leadership in chemical research and the conviction that participation in original research is the best way to awaken, develop, and give direction to creativity, a philosophy that has permeated the Division of Chemistry and Chemical Engineering since its founding.

The program is designed to encourage students to begin their research early in their first year. Students can elect to do research that crosses the boundaries of traditionally separate areas of chemistry, for in this relatively compact division, they are encouraged to go where their scientific curiosity drives them. A thesis that involves more than

one adviser is not uncommon, and interdisciplinary programs with biology, physics, geology, chemical engineering, and environmental science and engineering science are open and encouraged.

To accommodate the needs of interdisciplinary research programs, the program is divided into two tracks: Chemistry; and Chemical Biology & Molecular Bioscience (CB&MB). The two tracks differ in the timing of rotations, choosing research advisor(s), and teaching, but otherwise have the same requirements for completion of the Ph.D. degree.

An extensive program of seminars will enable students to discover and discuss notable work in chemical physics, organic chemistry, inorganic chemistry and electrochemistry, organometallic chemistry, chemical biology, and biochemistry and molecular biophysics. Graduate students are also encouraged to attend seminars in other divisions.

Ch Learning Outcomes

Students upon whom are conferred the Ph.D. degree have provided evidence of independent scholarship and scientific creativity through the performance of original research, which is described in their doctoral thesis and defended orally. Students must also demonstrate an ability to conceive new research directions by preparing and defending a set of written research propositions.

Ch Course Program

A student is required to complete at least five courses, each being nine units or more, in science or engineering. CB&MB students are expected to take Ch/Bi 110a or demonstrate completion of an equivalent course in college. At least one course must be in a field substantially outside the research area of the student. Courses may be either inside or outside the chemistry option, must be numbered 100 or greater, and must be taken on a letter-grade basis with a grade of B or above. The student should discuss, with their adviser, which courses best serve their individual needs. The program of courses must be approved by the research adviser and by the Chemistry Graduate Study Committee.

Ch Master's Degree

Students are not ordinarily admitted to graduate work leading to an M.S. degree. Under special circumstances, and with prior approval of the Graduate Study Committee, a master's degree can be obtained. All master's programs for the degree in chemistry must include at least 45 units of chemical research and must satisfy the Course Program described above. The remaining electives may be satisfied by advanced work in any area of mathematics, science or engineering, or by chemical research. A satisfactory thesis describing this research, including a one-page digest or summary of the main results obtained, must be submitted to the divisional graduate studies office at least 10 days before the degree is to be conferred. In addition, the fulfillment of the thesis requirement must be signed off by a designated faculty member on the M.S. candidacy form and a final copy of the thesis

submitted to the Graduate Office no later than two weeks before the degree is to be conferred. The copies of the thesis should be prepared according to the directions formulated by the dean of graduate studies and should be accompanied by a statement of approval of the thesis, signed by the adviser directing the research and by the chair of the Chemistry Graduate Study Committee.

Ch Degree of Doctor of Philosophy

Selecting a Research Project
Soon after a new graduate student arrives at Caltech, they attend a series of orientation seminars that introduce students to the active research interests of the faculty. Students are strongly encouraged to meet with faculty whose fields attract them, to attend group meetings, and to discuss in detail potential research projects.

Students are required to complete a minimum of two rotations in different research groups of their choice before committing to an advisor-advisee relationship (exceptions to rotate in the same group twice are dissuaded but may be approved on rare occasions by submitting a petition to the division). Students in the Chemistry track generally participate in two 4-week rotations. The opening date for Chemistry track students to join a research group is December 1st. CB&MB students must participate in at least two 10-week rotations and may join a group at the end of the winter term. Both tracks permit additional rotations. Through these rotations, students eventually settle upon the outlines of a research problem that interests them and select a specific research advisor (or set of co-advisers).

Candidacy
To be recommended for candidacy for the doctor's degree in chemistry, a student must demonstrate an understanding and knowledge of the fundamentals of chemistry and give satisfactory evidence of proficiency at a high level in the primary field of interest, as approved by the division. This is accomplished by an oral candidacy examination, which must be held during or before the sixth term of graduate residence (excluding summer terms). The candidacy committee shall consist of the thesis adviser(s) and two additional faculty members; at least two of the three members must be chemistry faculty. The committee should be considered as a resource for the student for the remainder of their studies. At the candidacy examination, a student is asked to demonstrate scientific and professional competence and promise by discussing a research report and propositions as described below.

The research report should describe progress and accomplishments to date and plans for future research. Two original research propositions, or brief scientific theses, must accompany the report, and at least one must be well removed from the student's field of research. These propositions should reflect familiarity with the literature, originality, and ability to pose and analyze suitable scientific research problems. The research report and propositions must be in the hands of the examining committee as either an electronic pdf file

or a bound, hard-copy document one week before the examination.

The result of the candidacy examination may be either (a) pass, (b) fail, or (c) conditional. Conditional status is granted when the committee decides that deficiencies in a student's research report, propositions, or overall progress can be remedied in a specific and relatively brief period of time. In order to change conditional to pass status, the student must correct the indicated deficiencies or in some cases schedule a new examination the following term. The student must be admitted to candidacy at least three terms before the final oral examination (i.e., thesis defense). A student cannot continue graduate work in chemistry (nor can financial assistance be continued) past the end of the sixth term of residence (e.g., spring term of the G2 year) without being admitted to candidacy, except by petitioning the division for special permission. This permission, to be requested by a petition submitted to the Graduate Study Committee stating a proposed timetable for correction of deficiencies, must be submitted before registration for each subsequent term (including the summer following the sixth term of residence) until admission to candidacy is achieved.

Graduate Teaching Assignment Duties

All Ph.D. students are required to perform a minimum of one 9 term-hour GTA within the chemistry option before the completion of the fourth year of study. In practice, students are expected to perform three GTAs during the G1 and G2 years. Chemistry track students generally serve as TAs during the fall, winter, and spring terms of the G1 year, while CM&MB students generally serve as TAs during the spring term of the G1 year and during the fall and winter terms of the G2 year. Additionally, students may serve as GTAs in subsequent years of study, with their advisor's approval. Most students find the teaching assistantship a valuable experience for their future careers.

Language Requirement

There is no formal foreign language requirement for the Ph.D. in chemistry. However, the division believes strongly in the professional importance to chemists of knowledge of foreign languages and encourages their study prior to graduate work or while in graduate school.

Ph.D. Thesis Committee

Following admission to candidacy, the student will form their Ph.D. committee in consultation with their advisor. This committee will comprise at least four faculty members and will generally consist of the original candidacy committee plus an additional member of the faculty; at least three of the members must be from the CCE Option.

Annual Meetings requirement

The student must meet with their committee annually, beginning in the third year. Students who do not meet this requirement will not be able to register for future terms except by submitting a petition to the division. At these informal meetings, the student will update the committee on the status of their research.

Typically, a student will provide an updated CV, a short research summary (2-3 pages), and a brief outline of plans for the coming year. Upon successful completion of each annual meeting, students will enter their meeting data in REGIS.

If the student has not progressed sufficiently, completion of the Ph.D. may be considered inappropriate.

Fourth Year Progress Meeting

Before the 13th academic term of graduate residence (excluding summer terms, i.e., end of the G4 year), the student will be expected to demonstrate satisfactory progress in the course of thesis research. To this end, an informal meeting with the Ph.D. thesis committee will be held. Typically, a student provides an updated CV, a short research summary (2-3 pages), a thesis outline with %-completed for each chapter, and a timeline for completion of the degree. At the meeting, the student will likely present an oral summary of research completed to date as well as an outline of future research plans. Following the discussion, an appropriate timetable for completion of the degree requirements will be discussed and agreed upon. It is also common to discuss plans for post-Caltech at the meeting.

Length of Graduate Residence

Any graduate student who anticipates a need to register for a 24th term must hold a meeting of their thesis committee and present the institute-required petition for permission to register that includes a plan of action for the period of the requested registration and a specific date for the completion of the degree requirements. This petition must be approved by the Thesis Committee, by the chair of the Chemistry Graduate Study Committee and, in cases where financial support is an issue, by the executive officer or division chair, before it is forwarded to the dean of graduate studies. Financial support of graduate students who are required to petition to register will not normally be provided through teaching assistantships. Failure to complete the degree requirements by the date specified in the petition would require the entire approval process to be repeated. This process must be repeated for every subsequent year.

Thesis and Final Examination

The final examinations consist of two parts: (i) a propositions exam; and (ii) a Ph.D. thesis defense.

For the propositions exam, three original research propositions are required. No more than one of these may be a carryover from the candidacy examination, and at least one must be well removed from the field of research. Each proposition must be presented in writing with adequate documentation. The propositions should display originality, breadth of interest, and soundness of training; a student will be judged on the selection and formulation of the propositions as well as on the defense of them. Formulating a set of propositions should begin early in the course of graduate study.

To emphasize the importance of these propositions, there will be a separate examination on the three propositions by the Ph.D. thesis

committee. This examination on the propositions is normally taken after the thesis research progress meeting, but not less than 10 weeks in advance of the final doctoral examination. A copy of the propositions, along with suitable abstracts, must be submitted to the examining committee not less than two weeks before the propositions examination. These propositions must be acceptable to the committee before the final doctoral examination can be scheduled.

For the Ph.D. thesis defense, a copy of the thesis must be submitted to each member of the thesis committee not less than two weeks before the final doctoral examination. A copy of the thesis should also be submitted to the Institute Graduate Office for proofreading no less than two weeks prior to the final doctoral examination.

In order to complete the Ph.D. degree requirements, the student must not only pass the oral thesis defense but also upload a final, approved version of the thesis to the CaltechTHESIS.

Ch Subject Minor

Graduate students in other options taking chemistry as a subject minor will be assigned a faculty adviser in chemistry by the Chemistry Graduate Study Committee. In consultation with this adviser, the student will work out an integrated program of courses, including at least 45 units of formal course work at the 100 level or above. This program must be approved by the Chemistry Graduate Study Committee, and a grade point average of 3.0 in the approved program will be required.

CIVIL ENGINEERING (CE)

Aims and Scope of the Graduate Program

Civil Engineering (CE) research and study are offered through the Department of Mechanical and Civil Engineering (MCE). The degrees of Doctor of Philosophy (Ph.D.) and Master of Science (M.S.) are offered. In general, students who intend to work full-time toward the Ph.D. degree as a final degree objective are admitted to the Civil Engineering Graduate Program. The M.S. degree is typically only awarded to students who pursue the Ph.D. degree in civil engineering at Caltech and who do not already have an M.S. degree in civil engineering.

The aim of the graduate program in civil engineering at Caltech is to prepare students for research and professional practice in an era of rapidly advancing interdisciplinary technology. The program combines individual depth of experience and competence in a particular chosen major specialty, with a strong background in the basic and engineering sciences. It strives to develop professional independence, creativity, leadership, and the capacity for continuing professional and intellectual growth.

CE Preparation for the Graduate Program

Entering graduate students are expected to have a thorough background in undergraduate mathematics, physics, and engineering. While a strong undergraduate program in civil engineering should provide a suitable preparation, students who have not specialized in civil engineering as undergraduates may also be admitted for graduate study. For example, an outstanding four-year undergraduate program in mathematics and sciences may provide a suitable background as well. The qualifications of each applicant will be considered individually, and, after being enrolled, the student will arrange their program in consultation with a member of the faculty.

CE Master's Degree

The degree of Master of Science in civil engineering is only awarded to students who do not already have an M.S. degree in civil engineering. The degree will be awarded upon request by students who have fulfilled the requirements. Only in exceptional cases is there admission to the M.S. program as the final degree objective.

A minimum of 138 units of courses numbered 100 or above, which meet the required master's program listed below, must be passed with a grade of at least C for completion of the master's degree in civil engineering. All units must be taken for grades, except for courses offered only on a pass/fail basis. The M.S. degree in civil engineering is typically completed within the first two years of residency at Caltech.

Each student's program must be approved by the adviser and option representative in mechanical and civil engineering before registering for the course.

Required Master's Program

1. Graduate civil engineering core (45 units). These units should provide a solid base for the student's engineering interest. The courses should be selected from the Core CE subjects listed under the of the Degree of Doctor of Philosophy Description and Requirements section.
2. Mathematics, engineering, and research electives, except seminar courses (63 units). Research can be included up to a maximum of 27 units.
3. Free electives (27 units). Any course with a number of 100 or greater may be selected, except that research units and seminar courses can not be included.
4. Graduate Engineering Seminar, AM/CE/ME 150 abc (3 units).

CE Degree of Doctor of Philosophy

The Ph.D. degree in civil engineering is focused on research. Study and research programs for the Ph.D. degree are individually planned to fit the interests and background of the student. A comprehensive research project resulting in an original contribution to the field, which is documented by a thesis, is required. Institute requirements for the Ph.D. degree are described in the section on degree requirements. A minimum of three academic years in residence as a graduate student are required by the Institute, and two or more additional years are

usually needed for preparation of the thesis.

Advising and Thesis Supervision
An interim adviser is appointed for each student upon admission to a graduate degree in civil engineering. The interim adviser will serve as the primary mentor until the student finds a research adviser. It is the responsibility of the student to find an academic and research adviser within three terms of graduate residence at Caltech. In consultation with the adviser, the student must form a Ph.D. Thesis Advisory Committee within four terms of graduate residence at Caltech. This committee shall consist of at least three members of the Caltech professorial faculty, with at least two members from the faculty in mechanical and civil engineering. The committee shall meet as requested by the student. Further, the committee shall meet annually to review progress and to approve the registration of the student beyond the fifth year of graduate residence at Caltech.

The adviser and the Thesis Advisory Committee provide the majority of mentoring to the student. In addition, the Option Representative and other members of the faculty are always available to provide advice and mentoring on any aspect of research, progress toward the Ph.D., future careers, and other aspects of graduate school.

Admission to Candidacy
To be recommended for candidacy for the Ph.D. degree in civil engineering, the student must, in addition to meeting the general Institute requirements, do the following:

- Obtain the agreement of a professorial faculty member to serve as the students academic and research adviser before the end of the third term of graduate residence at Caltech. In consultation with the adviser, the student must form a Ph.D. Thesis Advisory Committee before the end of the fourth term. This committee shall consist of at least three members of the Caltech professorial faculty, with at least two members from the faculty in mechanical and civil engineering.
- Pass both subject and research components of the oral candidacy examination before the end of the eighth term of graduate academic residence at Caltech. If the student has chosen a subject minor, an examination on the subject of that program may be included at the request of the discipline offering the subject minor.
- Complete a minimum of 195 units of courses numbered 101 or above, that fulfill the required Ph.D. program listed below. All units must be taken for grades and passed with a grade of at least a C, except for courses offered only on a pass/fail basis. The course work towards the Ph.D. degree in civil engineering is typically completed within the first three years of residency at Caltech.

Required Ph.D. Program

1. Civil Engineering Core Subjects (45 units): Course work in core subjects selected from the list below; pass with a grade of at least C: Ae/APh/CE/ME 101 abc, Ae/AM/CE/ME 102 abc, AM/CE 151, Ae/Ge/ME 160 ab, Ae/CE 165 ab, ME/CE/Ge 174, Ae/AM/MS/ME 213, Ae/AM/CE/ME 214, Ae 220, Ae/CE 221, ME/MS/AM 221, Ae/AM/ME 223, AM/CE/ME 252, ME/Ge/Ae 266 ab.
2. Electives or Minor (63 units): Additional engineering or science courses with course number 101 or above, except seminar or research courses. ACM 100 can be taken as an elective with the advisor's approval. Pass with a grade of at least C, courses that are approved by the Thesis Advisory Committee. These courses are intended to provide further depth and incorporate breadth. These units can be used to satisfy a minor requirement in another option.
3. Advanced mathematics or applied mathematics (27 units): Pass with a grade of at least C, chosen in consultation with adviser from the following list: ACM 101 or higher, CDS 232, Ma 108 or higher, Ph 129. The requirement in mathematics is in addition to the requirements above.
4. Graduate engineering seminar (6 units): Six terms of AM/CE/ME 150 abc, within 12 terms or 3 years in residence at Caltech.
5. Research (54 units): Successfully complete at least 54 units of research and demonstrate satisfactory research progress.

Registration Beyond the Sixth Year of Graduate Residence

The annual approval of the Ph.D. Thesis Advisory Committee is necessary for registration beyond the 24th academic term of graduate residence at Caltech.

Thesis and Final Examination

The thesis examination will be given after the thesis has been formally completed. This examination will be a defense of the doctoral thesis and a test of the candidate’s knowledge in the specialized field of research. The format of the examination can be chosen from the following two options, by the student, in consultation with the students research adviser: (i) a public seminar presented by the candidate, with an open question period, followed by a private examination by the Examining Committee or (ii) a private presentation to the Examining Committee followed by the examination, with a public seminar on another date. The Examining Committee shall consist of a minimum of four voting members, three of whom must be Caltech faculty; two members must be from MCE. The Thesis Defense Committee shall be chaired by a committee member who is an MCE Caltech professorial faculty member and not the student’s adviser.

CE Subject Minor
A student majoring in another branch of engineering or another division of the Institute may, with the approval of the faculty in the Department of Mechanical and Civil Engineering and the faculty in the students major field, elect civil engineering as a subject minor. The program of courses must differ markedly from the major subject of study or research, and must consist of at least 54 units of advanced courses (101 or above) approved by the faculty in mechanical and civil engineering.

COMPUTATION AND NEURAL SYSTEMS (CNS)

CNS Aims and Scope of the Graduate Program
An integrated approach to graduate study combining computation and neural systems is organized jointly by the Division of Biology and Biological Engineering, the Division of Engineering and Applied Science, and the Division of the Humanities and Social Sciences. This curriculum is designed to promote a broad knowledge of aspects of molecular, cellular, and systems biology, cognitive neuroscience, computational biology and computational neuroscience, information and learning theory, emergent or collective systems, and computer science and electrical engineering in conjunction with an appropriate depth of knowledge in the particular field of the thesis research. For more details, see cns.caltech.edu.

Admission
Ideal applicants will have a Bachelor of Science degree or equivalent with a strong quantitative background and some facility with computer programming. They will have shown an interest in understanding the brain and/or in autonomous intelligent systems. The GRE tests (general and advanced subject) are not required and scores will not be considered for admission.

Advisory Committee and TA Requirement
An advisory committee of three CNS faculty members is constituted for each student by the CNS admissions committee upon admission to the program. The faculty in whose lab the student is staying first chairs this committee. The advisory committee meets with the student when they arrive, guides and approves first-year course choices, and answers questions and offers advice about the program and the way of life in CNS. The CNS faculty are available to students during the year for formal and/or informal discussions.

It is expected that each graduate student will serve as a teaching assistant in one or two CNS courses during their residency at Caltech as part of the Ph.D. graduation requirement.

CNS Master's Degree

Only students who expect to pursue the Ph.D. degree will be admitted to the option. The master's degree may be awarded in exceptional cases. The awarding of this degree requires fulfilling the Institute requirements for a master's degree, satisfying the option breadth requirements (see following section), the completion of a master's thesis, and receiving from a candidacy examination oral committee a recommendation for awarding the degree.

Laboratory Rotations

Mandatory rotations through research groups (labs) provide a unique opportunity for the student to experience the CNS culture. To broaden the student's knowledge and to provide familiarity with different techniques and ways of thinking or doing research, each student should carry out three 12-week laboratory rotations (one per term) during the first year, and should engage in research. During each rotation, the student is expected to take part in the life and routine of the lab by attending lab meetings, participating in research projects and discussions with members of the lab, and meeting monthly with the faculty of that lab to discuss science.

Course Requirements

Six nine-unit courses are required during the first year: CNS/Bi/Ph/CS/NB 187, either Bi 9 or equivalent, or NB/Bi/CNS 150, a neurobiology or modeling course, a math course, and two other CNS, Bi, EE, ACM, or Ph courses (for example, a schedule of CNS/Bi/EE/CS/NB 186, CNS/Bi/Ph/CS/NB 187, NB/Bi/CNS 150, and CS/CNS/EE 156 satisfies this requirement). CNS students are required to take two additional classes: the one-unit survey course CNS 100, and the four-unit course Bi 252. These eight courses must be taken for letter grades. Students are free to take additional classes, and a research adviser may require that a student take a specific, complementary course as a requirement for joining their lab.

Candidacy

Four faculty, including the three faculty in whose labs rotations have been done, should be on the student's candidacy exam committee. At the end of the first year, the student is expected to decide on a research group and begin work there. The first summer is thus expected to be spent entirely on research in that lab. To be recommended for candidacy you are required to pass two tests: the general knowledge exam, and the research and candidacy exam. These exams are supervised by the CNS option representative.

G1 students are required to take an oral breadth exam where they have to demonstrate breadth of knowledge on CNS related topics. The examining committee is composed of four faculty. The student is required to contact the faculty and arrange the composition of the exam committee and the date of the exam (typically in June of the first year and no later than the fall term of the second year). The student should consult with each committee member about the range of topics they should prepare for. Often the members of the committee are

faculty in whose labs the student rotated and/or faculty that the student took classes from. Students do not need to complete all courses before taking this exam.

This is an oral exam with the four faculty (including the heads of the student's three rotation labs and one other chosen for "breadth,'' of whom one can be from outside Caltech). It should be scheduled by the student (who contacts the committee members) to take place during the last six weeks of the third term of year one. For the exam, the student must answer questions (from more than one category) taken from the list, which is modified each year. (The exam can be retaken after three months.)

The research and candidacy exam satisfies the depth requirement. During year two, the student is expected to produce a piece of work of a quality sufficient to be presented at a professional meeting. (The objective of this description is to offer a way to calibrate the level of expected research achievement and involvement. Professional acceptance of the abstract or paper is not a requirement for passing candidacy.) This work is presented in an oral exam in spring term of year two, before the same exam committee (if possible) that conducted part one of the exam. The exam focuses exclusively on research (accomplished and/or planned). During year two, the student may take other courses, as needed, but is expected to present a high standard (quality, originality) of research at the time of this second part of the candidacy exam.

Thesis Advisory Committee

Once admitted to candidacy, the student chooses a Thesis Advisory Committee of at least three faculty. This committee serves as a source of advice independent of the Ph.D. adviser throughout the student's tenure. Each year, before the end of June, the student delivers a written progress report, followed by a meeting with the Thesis Advisory Committee.

Thesis Examination Committee

This committee should consist of a minimum of four voting members, three of whom must be Caltech faculty. The final oral examination covers principally the works of the thesis, and according to Institute regulations must be held at least three weeks before the degree is to be conferred.

CNS Subject Minor

Students majoring in other fields may take a subject minor in CNS, provided the program is supervised by a CNS adviser, is approved by the CNS option representative, and consists of 45 units, including NB/Bi/CNS 150, CNS/Bi/Ph/CS/NB 187, Bi 252, and other CNS cross-listed classes. A subject minor is not required for the Ph.D. degree in CNS.

COMPUTATIONAL SCIENCE AND ENGINEERING (CSE)

Aims and Scope of the Minor

Computational science and engineering (CSE) may be pursued as a subject minor by graduate students who are pursuing Ph.D. degrees in any option. The CSE minor is intended to supplement one of Caltech's graduate degrees and is designed for students who wish to broaden their knowledge of CSE beyond their major field of study. The CSE minor is also intended to recognize graduate students' interest in and dedication to CSE as demonstrated by the successful completion of a program of study in the field. Completion of the CSE minor program of study will be recognized on the Ph.D. diploma by the statement, "…and by additional studies constituting a minor in Computational Science and Engineering."

Requirements

To receive the CSE minor, graduate students must fulfill the following requirements.

- 18 units (two terms) from the following list: ACM/EE 106 ab, CMS/ACM/EE 122, ACM 114 ab, ACM 116, ACM 117, ACM 157, ACM 158, ACM 210 ab, ACM/IDS 216.
- 18 units (two terms) from the following list: CS 115, CS 138 abc, CMS/CS 139 abc, CS 143, CS/IDS 150 ab, CMS/CS/CNS/EE/IDS 155, CS/CNS/EE 156 a, CS 179.
- 9 units (one term) from the list: Ae/AM/CE/ME 214, Ae/AM/ME 232 ab, Ay 199, Ch 121 ab, GE 263, Ph/CS 219 abc.

All courses to be applied toward the CSE minor requirements must be taken on a graded basis, and students must obtain a grade of B or higher in all courses. Courses that are used to satisfy the CSE minor cannot be used to satisfy course requirements in the major options unless absolutely required by the option. Courses taken as part of the CSE minor are counted toward the total number of units required for the completion of the Ph.D. degree.

CSE Minor Administration

The CSE minor is administered by an oversight committee consisting of three faculty members reporting to the chair of the engineering and applied science division. In consultation with their advisers and, if needed, with the CSE Oversight Committee, students formulate a program of approved courses individually tailored to each student's background and needs, with the objective that the student achieve a level of competence in specific subjects relevant to CSE. Students must petition the CSE Oversight Committee for approval of their program of study. Upon completion of the program of study, the CSE Oversight Committee will verify that the CSE minor requirements have been fulfilled.

COMPUTER SCIENCE (CS)

Aims and Scope of the Graduate Program
Graduate study in computer science within the Computing & Mathematical Sciences department is oriented principally toward Ph.D. research. The Ph.D. program requires a minimum of three academic years of residence; required coursework is generally completed within the first two years. Students must maintain high academic standards during their graduate residence. A student's Ph.D. research must exhibit originality in the formulation, analysis, and solution of a problem that is significant to the field of study. The option representative and executive officers are available to discuss concerns regarding academic progress.

CS Master's Degree
The CS Option only admits students who plan to pursue the Ph.D. degree. The M.S. degree may be awarded in exceptional cases at the discretion of the CS Option Representative. To be eligible, students must complete the following requirements:

- All Institute M.S. requirements;
- The classwork requirements for the CS Ph.D. program;
- Recommendation to award the M.S. from the CS preliminary examination committee.

CS Degree of Doctor of Philosophy

Course requirements
Students must complete a minimum of 135 units of courses numbered 100 or greater, including research units (CS 280). Students should consult with their adviser to ensure balance in the selected courses.

The coursework must include:

- CMS 290 is required for all first year CS graduate students during each term (fall/winter/spring).
- Advanced courses in computer science. Completion of a minimum of 54 units of CS courses numbered 100 or greater in addition to units earned for reading, research, and independent projects. Up to 24 of the 54 units may be taken from non-CS courses from CMS or ACM, including CMS/ACM/IDS 107, CMS/ACM/EE 122 and CMS 117, or other courses with approval from the option representative.
- Completion of a minimum of 27 additional units of coursework (not including research units) labeled 100 and above, in any academic discipline.

Preliminary examination
Toward the end of the first year, all incoming students must take a preliminary examination administered by the faculty. Its purpose is to ensure a solid and broad knowledge in computer science, and in the event of a deficiency, to direct the students to necessary courses and reading.

Candidacy
To be recommended for candidacy, a student must have completed the required coursework, have passed the preliminary examination, have entered upon a course of research approved by their thesis adviser, and have passed a candidacy oral examination. The candidacy oral examination is administered by a committee that consists of four faculty that is approved by the option representative. The chair of the committee must be a Caltech professorial faculty member distinct from the adviser. The examination ascertains the student's breadth and depth of preparation for research in the chosen area. The candidacy examination should be taken within the first three years of graduate study.

Advising and Thesis Supervision
In order to facilitate close supervision and a highly research-oriented environment, each student is admitted directly to an adviser and research group. A course of study is determined in consultation with the adviser. Occasionally students will be admitted into more than one group. Changes in affiliation may occur with the common consent of the student, the new adviser, and the option representative.

Students meet regularly with their adviser throughout their time at Caltech, and are encouraged to do the same with other members of the faculty.

Academic progress will be reviewed regularly, including at least once annually by the option representative.

An ability to explain concepts and to verbally present one's work is vital to a successful career in research and/or teaching. To this end, students may be required by their advisor and the option representative to occasionally serve as a teaching assistant.

Thesis and Final Examination
A final oral examination will be scheduled and given after the Ph.D. thesis has been submitted for review to the student's adviser and thesis committee; the latter consists of at least four faculty approved by the option representative. The chair of the committee must be a Caltech professorial faculty member distinct from the adviser. The thesis examination is a defense of the thesis research and a test of the candidate's knowledge in their specialized fields.

Subject Minor in Computer Science
A subject minor is not required for the Ph.D. degree in computer science. PhD students majoring in other fields may take a subject minor in computer science consisting of 45 CS units numbered 100 or greater. The minor must be supervised by a computer science faculty adviser and approved by the computer science option representative,

a year in advance of graduation. The courses must be sufficiently removed from the student's major program of study and must include CS 138 (CS 139 may be substituted) unless the student has previously taken an equivalent course. The courses in the plan must be taken for grades and the student is required to achieve an A- average in them.

COMPUTING AND MATHEMATICAL SCIENCES (CMS)

Aims and Scope of Graduate Program
Algorithmic thinking is emerging as a fundamental tool for all researchers, not just computer scientists. Algorithmic thinking now drives disciplines ranging from statistics and electrical engineering to biology and physics to economics and the social sciences. Computing and Mathematical Sciences (CMS) is an interdisciplinary Ph.D. program that trains students to apply algorithmic thinking to problems across science and engineering. Our research mission is to build the mathematical and algorithmic foundations required to move from data to information to action. Students will study structures and mechanisms that store, process, and communicate information and that make decisions based on this information. These systems may be expressed in silicon and called computers, in lines of code called programs, or in abstract notation called mathematics. They may appear in economics as markets or social networks, as sequences of amino acids in DNA, or in the organic structure of the human brain.

CMS Master's Degree
Only students who expect to pursue the Ph.D. degree will be admitted to the option. The master's degree may be awarded in exceptional cases. The awarding of this degree requires fulfilling the Institute requirements for a master's degree, satisfying the core course requirements, and receiving a recommendation for awarding of the degree from the preliminary exam committee.

CMS Degree of Doctor of Philosophy
Institute requirements for the Ph.D. degree are described in the section on degree requirements. Approximately two years of coursework are required, and two or more years are usually needed for preparation of the dissertation.

CMS Admission to Candidacy
To be recommended for candidacy for the Ph.D. degree in computing and mathematical sciences the student must, in addition to meeting the general Institute requirements, do the following:

Core requirement
Each student will take six core CMS classes, three in applied mathematics (ACM) and three in Computer Science (CS). In both fields, at least two of the three classes will be taken the first year to prepare for the preliminary examination, while the remaining classes will be completed by the end of the student's second year. The core CMS classes are CMS/ACM/IDS 107, CMS/ACM/EE 122, CMS/ACM 117, CMS/CS/IDS 139, CMS/CS/EE/IDS 144, CMS/CS/CNS/IDS 155.

These classes must be taken for a grade.

Depth requirement: At least 27 units of courses in one particular subject area will be completed for a grade. The plan for these 27 units must be approved by the CMS option representative.

Breadth requirement: At least 27 units of advanced courses in mathematics, engineering, science, or social science will be completed for a grade. The plan for these 27 units must be approved by the CMS option representative.

Preliminary Examination

All students must pass a preliminary examination on material from two CMS core classes in applied mathematics and two CMS core classes in computer science. The examination is administered by a committee consisting of at least three faculty selected by the CMS option representative. The exam will occur during the student's first year.

Candidacy Examination

All students must pass an oral candidacy examination to ascertain the breadth and depth of preparation for research in the chosen field. The examination will be administered by a committee that consists of at least four faculty, that is approved by the CMS option representative, and that satisfies Institute regulations. In particular, the chair of the candidacy committee must a faculty member distinct from the student's research adviser. The examination will occur during the student's first three years.

CMS 290 is required for all CMS first-year graduate students during each term (fall/winter/spring).

Advising and Thesis Supervision

Upon admission, each student will be assigned a primary adviser in the option. This adviser will be replaced by a research adviser (possibly the same faculty member) once a direction of specialization is determined, and not later than the beginning of the second year. After completion of the candidacy exam, each student will form a thesis committee (possibly the same as the candidacy committee) that consists of at least four faculty, that is approved by the CMS option representative, and that satisfies Institute regulations. In particular, the chair of the thesis committee must be a faculty member distinct from the student's research adviser. The thesis committee will meet as needed, but no less than once a year, in order to advise the student.

Academic progress will be reviewed regularly, including at least once annually by the option representative.

An ability to explain concepts and to verbally present one's work is vital to a successful career in research and/or teaching. To this end, students may be required by their advisor and the option representative to occasionally serve as a teaching assistant.

A final oral examination will be scheduled and given after the Ph.D. thesis has been submitted for review to the student's adviser and thesis committee. The thesis examination is a defense of the thesis research and a test of the candidate's knowledge in their specialized fields. Normally, the defense will consist of a one-hour public lecture

followed by an examination of the thesis by the thesis committee.

CONTROL AND DYNAMICAL SYSTEMS (CDS)

Aims and Scope of the Graduate Program
The option in control and dynamical systems (CDS) is open to students with an undergraduate degree in engineering, mathematics, or science. The qualifications of each applicant will be considered individually, and, after being enrolled, the student will arrange their program in consultation with a member of the faculty. In some cases the student may be required to make up undergraduate deficiencies in engineering science courses.

The CDS option, as part of the Computing and Mathematical Sciences department, emphasizes the interdisciplinary nature of modern theory of dynamical systems and control. The curriculum is designed to promote a broad knowledge of mathematical and experimental techniques in dynamical systems theory and control. In addition to taking courses in the CDS option, students must select a focus area (see below).

CDS Master's Degree
Students will be admitted to the option who expect to pursue the Ph.D. degree. The master's degree may be awarded in exceptional cases. The awarding of this degree requires fulfilling the Institute requirements for a master's degree, satisfying the focus requirements, and receiving a recommendation for awarding of the degree from the candidacy oral examination committee.

CDS Degree of Doctor of Philosophy
Institute requirements for the Ph.D. degree are described in the section on degree requirements. Approximately two years of course work are required, and two or more years are usually needed for preparation of the dissertation.

Admission to Candidacy
To be recommended for candidacy for the Ph.D. degree in control and dynamical systems, the student must, in addition to meeting the general Institute requirements, do the following:

- Complete the following courses: CDS 131, CDS 232, and CDS 231 or CDS 233.
- Complete the following CMS/ACM courses: CMS/ACM/IDS 107a, and CMS/ACM/EE 122 or CMS/ACM 117.
- Complete an additional 36 units in CDS or other advanced courses in systems theory, dynamical systems, robotics, and/or applied mathematics.
- Complete the focus requirement, consisting of at least 27 units in a particular area outside of CDS. Courses taken to satisfy the focus must represent a coherent program of advanced study in the chosen area. Possible areas include biological systems, computer science, environmental science, fluid dynamics,

information and communications, networking, robotics, and space systems. The program of study must be approved by the student's counseling committee and the option representative.
- Preliminary examination. Toward the end of the first year, all incoming students must take a preliminary examination administered by the faculty. Its purpose is to ensure a solid and broad knowledge in control and dynamical systems, and in the event of a deficiency, to direct the students to necessary courses and reading.
- Prepare a research progress report.
- Pass an oral examination on the major topic of the student's research. The oral examination is normally taken no later than the end of the third year of graduate academic residence at the Institute.

In addition, CMS 290 is required for all CDS first year graduate students during each term (fall/winter/spring).

Advising and Thesis Supervision

Upon admission, each student is assigned an adviser in the option, who will approve the initial course of study by the student. A preliminary exam given during the first year of study will be used to evaluate the student's preparation for continued study.

The adviser will be replaced by a research adviser and a candidacy committee when the direction of specialization is determined, not later than the beginning of the second year. The candidacy exam is normally taken during the third year of study. The candidacy committee will be the judge of the completion of the engineering focus requirement, necessary before advancement to candidacy. The student's candidacy committee may be reconstituted as the thesis committee after the candidacy exam has been successfully completed.

At the early stages of thesis preparation, the student's thesis committee will meet as needed to advise the student of their progress and to deal with any problems that might have arisen.

A final oral examination will be given after the thesis has been formally completed. The thesis examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in the specialized field of research. Normally this defense will consist of a one-hour public lecture followed by an examination of the thesis by the thesis committee.

CDS Subject Minor

A student majoring in another option at the Institute may elect a subject minor in control and dynamical systems. The student must obtain approval from the CDS faculty of a course of study containing at least 54 units of courses that are required for the CDS Ph.D. (see Advancement to Candidacy) or advanced courses with a CDS listing.

ELECTRICAL ENGINEERING (EE)

Aims and Scope of the Graduate Program

Award of the Bachelor of Science degree may be followed by graduate study leading to the Master of Science degree in electrical engineering, and the more advanced degrees of Electrical Engineer or Doctor of Philosophy. Because admission to graduate studies in electrical engineering at Caltech is extremely competitive, the Admissions Committee attempts to select those applicants it judges both best qualified and best suited for the graduate program. Students are encouraged to submit the Graduate Record Examination (GRE) scores as part of the application package for the Ph.D. or M.S. degree programs in Electrical Engineering. Students who are unable to take the GRE in their home country will not be at a disadvantage due to the missing scores.

The Degree of Doctor of Philosophy offers two tracks: EE only and Medical and Electrical Engineering (Med-EE). The Med-EE track is offered jointly by both departments of Electrical Engineering and Medical Engineering (see MedE Section). The single degree to be shown on the diploma is "Ph.D. in Medical and Electrical Engineering."

EE Master's Degree

Normally, the master's degree in electrical engineering is completed in one academic year. The principal criteria for evaluating applicants for the MSEE are the excellence of their preparation for the math- and physics-oriented nature of Caltech's graduate courses, and the judgment of the Admissions Committee on their ability to successfully pursue and benefit from the course program. The Institute does not normally admit an applicant to the master's degree in a field in which the applicant already has a master's degree from another U.S. institution. Financial aid is seldom offered to those who intend to complete their graduate work with a master's degree. A joint B.S./M.S. degree is not available in electrical engineering.

135 units (100 or above) are required as approved by the electrical engineering graduate student adviser. No more than 30 units of pass/fail grades may be counted toward this requirement. Units toward this are not transferable from other schools. At least 54 units of EE letter-graded courses (courses listed or cross-listed as EE) labeled 100 or above are required. EE 105 ac and EE 102, Electrical Engineering Seminar, are also required. Students are urged to consider including a humanities course in the remaining free electives.

Students who have been admitted to the M.S.-only program must reapply if they are interested in the Ph.D. program.

EE Degree of Electrical Engineer

The engineer's degree may be awarded in exceptional cases. The awarding of this degree requires fulfilling the Institute requirements for an engineer's degree and receiving a recommendation for its awarding from the candidacy oral examination committee.

EE Degree of Doctor of Philosophy

As a rule, applicants who wish to undertake research work leading to a degree of Doctor of Philosophy in electrical engineering are admitted initially only for the MSEE. They are, however, evaluated according to additional criteria, the most important of which is the applicant's interestin and potential for research in one of the areas described below. The statement of purpose required as part of the application should clearly address this match. Considerable weight is also given to the opinions expressed in the applicant's letters of recommendation.

During the Ph.D. applicant's master's degree year, evaluation continues. It is based in part on performance in courses and in part on a qualifying oral examination scheduled early in the second quarter. As the year progresses, the electrical engineering faculty get to know the student, and the student makes contact with the professor in their area of research interest. Upon acceptance into a research group, the student begins research work and defers receiving the master's degree until formal admission into the Ph.D. program. If the Adviser is not an EE faculty member, the student should meet with the EE Option Representative and develop an oversight plan to monitor progress. Before the end of their third academic year of graduate study, the student takes the Ph.D. oral candidacy examination.

Financial aid available to a Ph.D. applicant includes teaching assistantships and fellowships. TA duties consist of grading papers or lab instruction but not classroom lecturing. A fellowship may be supplemented by a teaching assistantship, and either or both include a full tuition scholarship. Tuition scholarships alone are not available.

Admission to Candidacy

To be recommended for candidacy for the EE Ph.D. degree, the applicant must satisfy the following requirements (and pass the Ph.D. qualifying oral examination) no later than the end of the third academic year:

- Complete 18 units of research in their field of interest.
- Obtain approval of a course of study consisting of at least 135 units of advanced courses in electrical engineering or the related subjects approved by the Ph.D. adviser, with at least 54 units of letter-graded EE courses numbered 100 or above. No more than 30 units of pass/fail grades may be counted toward this requirement. The courses taken to satisfy the math requirement below and courses taken to fulfill the Master of Science degree requirement may be included to satisfy this requirement. Units toward this requirement are not transferable from other schools.
- Pass 27 units of mathematics courses, as approved by the student's research adviser, with letter grade no lower than C.
- Pass an oral candidacy examination.

Ph.D. Committee
The Ph.D. qualifying oral exam and the final defense exam are conducted by committees that are set up by the student and approved by the option representative. Members of these Ph.D. committees also serve as second or backup mentors in cases where such additional advising and problem solving are appropriate.

Thesis and Final Examination
The candidate is required to take a final oral examination covering the doctoral thesis and its significance in and relation to their major field. This final examination will be given no less than two weeks after the doctoral thesis has been presented in final form, and before its approval. This examination must be taken at least four weeks before the commencement at which the degree is to be granted. The committee must include the advisor, but another member of the committee must be selected as chair.

Advising and Thesis Supervision
Periodic meetings between the advising faculty and the graduate student are an integral part of the Ph.D. program. These meetings should be at sufficiently frequent intervals, as determined by the student and adviser. Students are also encouraged to meet with other members of the Ph.D. committee, the option representative, the executive officer, or Caltech's ombudsperson to discuss problems relating to satisfactory progress.

Med-EE Track Degree of Doctor of Philosophy

The track was established by Andrew and Peggy Cherng Department of Medical Engineering and the Department of Electrical Engineering at Caltech. The single degree to be shown on the diploma is "Ph.D. in Medical and Electrical Engineering".

Admission to candidacy
To be recommended for candidacy for the Med-EE Ph.D. program, each student must do the following.

- **Complete a minimum of 156 units of courses** . The MedE requirement of 21 units of MedE courses plus the EE requirement of 135 units must be met. Cross-listed MedE/EE courses can be double counted.
  - MedE course requirements
    - Complete the three-term seminar sequence, MedE 100abc (1 unit), with a passing grade.
    - Complete MedE 101a (9 units).
    - Complete a 9-unit MedE course.
      - Biodevices: BE/EE/MedE 189ab (12 and 9 units), MedE 201 (9 units), MedE 202 (9 units), or MedE/EE 204 (9 units).
      - Biomechanics/Fluidics: MedE/BE/Ae 243 (9 units), ChE/BE/MedE 112 (9 units), or ChE 103b (9 units).
      - Biomedical Optics: MedE/EE 168abc (9 units each).

        - Medical Imaging: MedE/EE 268 (9 units).
      - All required courses must be taken for grades and passed with a grade no lower than C, except for those courses offered only for pass/fail.
    - EE course requirements
      - Complete 135 units total with no more than 30 units of pass/fail.
      - Complete 54 units of letter-graded EE courses numbered 100 or above towards the 135-unit requirement.
      - Complete 27 units of mathematics courses, with letter grade no lower than C. Many math-related courses can count towards the requirement after confirming with your advisor.
      - Complete 18 units of research in your field of interest directed by your advisor.
- **Pass the oral qualifying and oral candidacy exams** of the Electrical Engineering department for students having chosen Electrical Engineering as the home department. Please refer to the MedE Section for the reciprocal requirement.

Thesis and final examination
The Med-EE Ph.D. thesis must be related to both options. The final thesis defense exam is conducted by a committee that is set up by the student and approved by the option representative of the home department. The committee must be composed of 2 members from each option. The committee must include the advisor, but another member of the committee must be selected as chair. The committee chair must be a Caltech Professorial faculty member. This final examination will be given no less than two weeks after the doctoral thesis has been presented in final form, and before its approval. This examination must be taken at least four weeks before the commencement at which the degree is to be granted. This thesis examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in their specialized doctoral research area.

EE Subject Minor
A student majoring in another option at the Institute may elect a subject minor in electrical engineering. The student must obtain approval from the electrical engineering faculty of a course of study containing at least 45 units (over the 100 level) of advanced courses with an EE listing (excluding 291). At least 36 of these should be for letter grades no lower than C. Undergraduate first-year classes cannot be counted toward this.

ENVIRONMENTAL SCIENCE AND ENGINEERING (ESE)

Aims and Scope of the Graduate Program
The ESE graduate program trains doctoral students to solve fundamental problems in environmental science and engineering. The problems cut across traditional disciplinary boundaries and span space scales ranging from global to local. Students are trained to acquire a broad base of knowledge of environmental systems, including Earth's atmosphere, oceans, and biosphere. They deepen their knowledge in one or more focus areas, culminating in research leading to a Ph.D. thesis. Reflecting the interdisciplinary nature of research in the ESE program, the program unites faculty from the divisions of Geological and Planetary Sciences, Engineering and Applied Science, and Chemistry and Chemical Engineering.

Admission
Applicants for admission to the ESE program should have undergraduate preparation in science, engineering, or mathematics. Admission is limited to students intending to pursue the Ph.D. degree. Only students who intend to work full-time toward the Ph.D. degree are admitted. The admission process follows Institute regulations.

International Students
In order to be admitted for graduate study, students from non-English-speaking countries are expected to read, write, and speak English and comprehend the spoken language. Although not required for admission, for applicants whose native language is not English or have not received a degree from a university or college where English is the primary language of instruction, it is important to demonstrate a strong capability in English prior to admission to Caltech. This can be done by self-reporting scores from the Educational Testing Service (TOEFL), Pearson Test of English Academic (PTE Academic), the Cambridge Examinations and the International English Language Testing System (IELTS), or other services that provide a certified English-language proficiency examination. The ESE faculty may also arrange an online interview while assessing applications.

Advising
An academic adviser is appointed for each incoming student to assist in designing their academic program. The research adviser is chosen by mutual agreement of the student and adviser during the second year of graduate study, after passing the Ph.D. qualifying examination. The Thesis Advisory Committee (TAC), consisting of four Caltech faculty members including the research adviser, should be constituted and meet with the student soon after the student passes the qualifying examination; thereafter, it should meet with the student annually to review progress and provide guidance and support. Committee membership may be changed if the student's research interests change. The TAC generally serves to recommend the student's advancement to candidacy; it may also serve as the examining

committee for the final thesis defense.

ESE Master's Degree
Students enrolled in the Ph.D. program may be awarded a master's degree if they have satisfied the basic Institute requirement of 135 units of work in courses numbered 100 or higher. These courses must include those specifically required in the ESE Ph.D. program.

ESE Degree of Doctor of Philosophy
For the Ph.D. degree, the student must (1) satisfy the course requirements, (2) pass the qualifying examination, (3) advance to candidacy, and (4) complete a thesis and successfully defend it in a final oral examination.

Course Requirements
During their first year, students, in consultation with their academic advisers, must design a program of graduate study that includes a minimum of 135 units of graduate work to be completed before the end of their third year. The course program should take into account the students' individual backgrounds and focus areas, educate them broadly in fundamental questions and methods of contemporary environmental science and engineering, and prepare them for their research. The course program must include the core courses ESE 101, 102, and 103. Attendance at the weekly research seminars (ESE 104 and 110 abc) is required for first-year students and is expected of all graduate students. All students are expected to have knowledge of methods of applied mathematics and statistics on the level of graduate courses at Caltech. In cases of unusual preparation, students may petition to substitute a similar but more advanced course for one of the required courses.

Additionally, students are required to take 36 units of elective courses from two of the three groups below:

- Environmental Biology: ESE/Bi 166, ESE/Bi 168, Ge/ESE 170;
- Environmental Chemistry: ESE/Ch 175, Ge/ESE 143, ESE/Ge/Ch 171;
- Environmental Physics: ESE 130-138, Ge/ESE 139, Ge/ESE 150, ESE/ChE 158.

The remaining units of graduate work can be fulfilled by a combination of elective courses in ESE or related disciplines, reading or laboratory courses (ESE 100), and research (ESE 106, 300). Of the total required 135 units, no more than 45 units may be in research. No more than 27 research units may be taken during the first year of graduate study. Exceptions may be granted by petition.

A grade of C- or better is required for all course work that satisfies these requirements.

It is expected that each graduate student will, as part of the Ph.D. graduation requirement, serve as a teaching assistant for one course per year, following completion of the qualifying exam.

Ph.D. Qualifying Examination
The Ph.D. qualifying examination must be taken during the first term of the student's second year of residency. This examination consists principally of an oral defense of two research propositions, each advised by a different faculty member. Written abstracts must be submitted for both propositions, and one of them must be described in the form of a research report or proposal. The qualifying exam also covers the material of the ESE core courses and of the elective courses the student has taken. In preparation for the qualifying examination, students are encouraged to register for nine units of research (ESE 106) in their second and third terms of residency.

Advancement to Candidacy
Students are recommended to advance to candidacy following the successful completion of a candidacy exam with their Thesis Advisory Committee (TAC). The exam, consisting of both a written Ph.D. thesis proposal and an oral presentation of this plan is required, and must be approved by all TAC members. Advancement to candidacy, including all required course work, should be completed before the end of spring term in the student's third year of residency.

Thesis and Final Examination
Copies of the completed thesis must be provided to the examining committee two weeks before the final oral examination. The final oral examination focuses on the work of the thesis and, according to Institute regulations, must be held at least two weeks before the degree is conferred.

ESE Subject Minor
Graduate students majoring in another option at the Institute may elect a subject minor in ESE. The ESE minor is intended to supplement one of Caltech's graduate degrees and is designed for students who wish to broaden and deepen their expertise with knowledge in ESE. To complete an ESE subject minor, graduate students must enroll in a program of study approved by the ESE option representative, which is to include at least 36 units over two or more terms of graduate-level ESE classes (ESE 100 and above) and 18 units over two or more terms of research under ESE 106 or ESE 300. At least one of the graduate-level ESE classes must be ESE 101, ESE 102, or ESE 103.

GEOLOGICAL AND PLANETARY SCIENCES (GPS) (GEOLOGY, GEOBIOLOGY, GEOCHEMISTRY, GEOPHYSICS, PLANETARY SCIENCE)

Aims and Scope of the Graduate Program
Students in the Division of Geological and Planetary Sciences study the earth and planets to understand their origin, constitution, and development, and the effect of the resulting physical and chemical characteristics on the history of life, on the environment, and on humanity. Broad training in the fundamental sciences enriched by more specialized course work within the division forms the basis of the

educational program. Students are encouraged to work with complex and often incomplete data sets, to undertake research in natural settings such as in the field or at sea, and to use the many modern laboratory facilities available within the division. Programs of study and research are pursued in environmental science and engineering, geobiology, geochemistry, geology, geophysics, and planetary science. The curriculum is flexible so that students with diverse degrees in science and engineering may carry out graduate work within the division. Interdisciplinary studies are encouraged and students may carry out academic and research programs within and between different divisions. The objective is to train students for future employment in academic research, government, and industry.

Admission and Entrance Procedures
Only students who intend to work full-time toward the Doctor of Philosophy (Ph.D.) degree are admitted. The admission process follows Institute regulations.

International Students
In order to be admitted for graduate study, students from non-English-speaking countries are expected to read, write, and speak English and comprehend the spoken language. Although not required for admission, for applicants whose native language is not English or have not received a degree from a university or college where English is the primary language of instruction, it is important to demonstrate a strong capability in English prior to admission to Caltech. This can be done by self-reporting scores from the Educational Testing Service (TOEFL), Pearson Test of English Academic (PTE Academic), the Cambridge Examinations and the International English Language Testing System (IELTS), or other services that provide a certified English-language proficiency examination. The GPS faculty may also arrange an online interview while assessing applications.

Based on their applications and interests, students enter one of the major subject options of the division and are given an academic adviser who is a professorial faculty member associated with the option. The six options are environmental science and engineering, geobiology, geochemistry, geology, geophysics, and planetary science. Students may later change options, but must first obtain approval from the new option. Each student must plan to satisfy the requirements for the Ph.D. degree in one option.

Entering students in the week preceding the beginning of instruction for the first term meet with their option representatives to discuss their preparation in the basic sciences and select a series of courses that will best prepare them for research in their chosen field while meeting the requirements set forth below.

First-year graduate students are encouraged to register for at least nine units of research (Ge 297) in each term of residence. The primary objective is to communicate to the students the excitement of discovery based on original investigations and to provide a broad scope of research aims. An important byproduct can be the

formulation of propositions for the Ph.D. qualifying oral examination or orientation toward Ph.D. research.

Advising and Thesis Supervision

The option representative for each incoming student will act as the academic adviser in the first term. An academic adviser will be assigned by the start of second term. This appointed adviser will continue as mentor with broad responsibility for a student's academic welfare throughout the graduate program. During the second year, after passing the qualifying examination, each student should identify a professor as thesis adviser, who will normally provide a graduate research assistantship and the opportunity for continuing research. In consultation with the two faculty advisers, each student then forms a Thesis Advisory Committee (TAC), composed of at least four Caltech professors (chaired by the academic adviser). External scientists closely involved in the student's research may also be appointed. Members of the TAC serve as advisers, counselors, and resources, and its membership may be changed if a student's research interests change.

The TAC meets with the student at least once each year for a progress review, and informally whenever the student needs or requests assistance or guidance. In addition, the faculty members in each option have their own systems for annual evaluations of student progress. A few months before completion of the thesis dissertation, the thesis examining committee will be chosen, usually including the members of the Thesis Advisory Committee.

All students are urged to consult with division faculty in the following sequence if they have any problems: thesis and academic advisers, Thesis Advisory Committee, option representative, academic officer, and division chair. If these division personnel cannot resolve a problem, then the student should turn to Institute offices.

GPS Master's Degree

Students enrolled in the Ph.D. program may be awarded a master's degree when they have satisfied the basic Institute requirement of 135 units. These courses must be part of a plan of study approved by the option representative, numbered 100 or higher, and part of those used to satisfy the Ph.D. requirement in one of the options of the division. A minimum of 72 units should be taken as courses, rather than research or independent study units. Specifically required are two courses from the list Ge 101, Ge 102, Ge 103, Ge 104, or ESE 101, ESE 102, ESE 103.

An application for admission to candidacy for an M.S. degree must be submitted in REGIS according to the academic calendar in the *Caltech Catalog*.

GPS Degree of Doctor of Philosophy

Division Requirements

For a Ph.D. degree, the student must 1) pass the qualifying oral examination, 2) satisfy course requirements of the division and of an option, and 3) complete a thesis and successfully defend it in a final oral examination. Recommendation to the dean of graduate studies for admission to candidacy occurs after the student has satisfied the first two requirements and has been accepted for thesis research by a division faculty member, who then becomes the student's thesis adviser.

The qualifying examination consists of oral and written defense of two research propositions, supplemented by a written description of one of them. Students are encouraged to consult with various faculty members concerning their ideas on propositions, but the material submitted must represent the work of the student. There must be a different faculty member associated with each of the two propositions. The exam is normally taken early in the first term of the second year of residence and is administered by the qualifying examination committee, which has members from the six options of the division. A more detailed outline of the qualifying examination is available on the division website.

By the end of the fall term of the second year, students are expected to select a thesis adviser(s) and before the end of the second year, the Thesis Advisory Committee will be selected, as outlined above. The division encourages students to engage in research early in their graduate careers. Students making normal progress will submit papers to refereed journals that have been approved by a faculty member of the division. The final oral examination for the doctorate by the thesis examining committee will be scheduled no sooner than two weeks following submission of the thesis (approved by the thesis adviser) and, in conformity with Institute regulations, it must be scheduled at least two weeks before the degree is to be conferred.

Candidates are expected to publish the major results of their thesis work. The published papers should have a California Institute of Technology address. Published papers may be included in the thesis.

By the end of the first academic year (third term): submission by the student of (1) tentative titles of propositions for review by the qualifying examination committee and (2) a list of courses planned to satisfy the Ph.D. requirement, for review by the option.

By the end of the second academic year: (1) passage of oral exam; (2) approval by the option of courses planned to satisfy candidacy requirements; (3) submission of a tentative thesis topic and adviser, and Thesis Advisory Committee.

By the end of the third academic year: (1) satisfactory completion of course requirements; (2) satisfactory completion of other requirements including selection of thesis topic and adviser, and Thesis Advisory Committee; (3) admission to candidacy. A student who has not been admitted to candidacy by the end of the third year will need permission of the academic officer to register.

By the end of the fourth academic year: satisfactory progress toward completion of thesis.

After completing the fifth academic year, the student must formally petition to register for each subsequent year. Financial aid will normally not be extended beyond the sixth year.

The student's program and progress will be reviewed annually by their option and by the Thesis Advisory Committee. In cases where, in the opinion of the faculty in the option, the student is clearly not showing adequate progress, they may recommend to the division chair that the student be denied permission to continue in the Ph.D. program based upon their overall assessment of the student's performance.

Basic Division Course Requirement

During the first year, every graduate student will take two of the seven basic introductory courses Ge 101–104 and ESE 101–103, in areas in which the student has not had substantial training. These should be completed during the first year. Throughout their graduate careers, students are expected to attend departmental seminars and seminar courses led by visiting scientists.

Beginning in the second academic year, students are required to serve as teaching assistants for one quarter per year they are in residence.

GPS Requirements of the Major Subject Options

Geobiology

In addition to the general Institute and basic division requirements, candidates for the Ph.D. degree in geobiology must successfully complete a minimum of 90 units at the 100 or greater level, including Ge 104; either Bi/Ch 110, Bi/CNS/NB 195, or Ge/ESE 118; and two courses from each of the following three subject menus:

- *Geology* : Ge 106, 112, 114 ab, 124 ab, Ge/ESE 125.
- *Chemistry:* Ge/ESE 143, 149, Ge 140 ab, ESE/Ge/Ch 171, 172, ESE/Ch 175.
- *Biology:* ESE/Bi 166, 168, Ge/ESE/Bi 178, Bi 117, ESE 103.

Other classes may be substituted for these menu requirements with the approval of the option representative. A student with substantial prior experience in geobiology (e.g., an M.S. degree) may use prior course work to substitute up to 45 of these units with the approval of the geobiology option representative. A grade of C- or better is required for all course work that satisfies these requirements. All students must have a basic knowledge of organic chemistry at the level of Ch 41 a. This requirement may be met by previous course work or through successful completion of this class. Geobiology students must complete one term (6 units) of Ge 109 (Oral Presentation) as an independent study with a faculty member of their choosing, typically the thesis adviser.

Geochemistry
In addition to general Institute and basic division requirements, candidates for the Ph.D. degree in geochemistry are required to take one term of Ge 109 in the geochemistry option and are required to demonstrate an understanding of the field through a total of 90 units of course work at the 100 level or higher spread over four of the subdisciplines offered in the option: petrology/mineralogy, isotope geochemistry, cosmochemistry, water chemistry/oceans, atmospheres, biogeochemistry, or advanced chemistry. A grade of C- or better is required for all course work that satisfies these requirements. All students must have a basic knowledge of chemistry at the level of Ch 21 and mathematics at the level of Ge 108. If appropriate, Ch 21 abc may be included as part of these units, and other courses below the 100 level may be included at the discretion of the option representative. With the approval of the geochemistry option representative, a student with substantial prior experience in some of the subdisciplines may use prior course work to substitute for up to 45 of these units and students entering with a master's degree in science or mathematics may be exempt from up to 45 units. In the oral candidacy exam, the student will be subject to examination in all four of the chosen subdisciplines.

Geology
The geology option requirements are (1) two of Ge 102, 103, 104, or ESE 101, ESE 102, ESE 103, which also satisfy the basic division requirement; (2) 36 units of advanced field geology, in the form of three terms of Ge 121 abc taken from three different instructors; (3) 54 additional units in 100- or 200-level science, math or engineering courses in any field at Caltech. Ch 21 abc may be included as part of these units, and other courses below the 100 level may be included at the discretion of the option representative. Courses that cannot be used to satisfy these requirements include research and reading courses, and certain courses constituting basic preparation in the field of geology, such as Ge 106, Ge 112, Ge 114 ab, and Ge 115 ab. A grade of C- or better is required for all course work that satisfies these requirements. Knowledge of basic physics, mathematics, and data analysis at the level of Ge 108 and Ge/Ay 117 is required of all Ph.D. candidates in geology. Students entering the geology option with a master's degree in a science or mathematics may be exempt from up to 45 units at the discretion of the option representative. Geology students are required to give a 30-minute presentation, including 10 minutes of discussion, on their research at the Geoclub Seminar series before admission to candidacy.

Geophysics
In addition to general Institute requirements, candidates for the Ph.D degree in geophysics must successfully complete the following: (1) two of the following basic introductory courses: Ge 101, 103, 104, or ESE 101–103, and one term of Ge 109 per year from the second year until the last year prior to obtaining the degree; (2) either Ae/Ge/ME 160 ab, APh 105 ab, MS 115, or a subject equivalent; (3) three of Ge

161, Ge 162, Ge 163, or Ge 164; (4) Ge 111 ab; (5) the choice between five additional 100- or 200-level science or mathematics courses or a minor in any field at Caltech (for example, computational science and engineering). It is highly recommended that (1)-(4) be fulfilled in the first year and (5) in the second year. A grade of C- or better is required for all course work that satisfies these requirements. Knowledge of basic data analysis at the level of Ge/Ay 117 is required of all Ph.D. candidates in geophysics. This requirement may be met by previous course work or through successful completion of these classes. Students may substitute another course for a required course if they can demonstrate to an option representative that they have already had the material in the required course.

Planetary Science
In addition to general Institute and basic division requirements, candidates for the Ph.D. degree in planetary science must satisfy the following course requirements: Ge 101, Ge 102, and courses in planetary formation and dynamics (Ge/Ay 133), planetary atmospheres (Ge/ESE 150), planetary interiors (Ge 131), and planetary surfaces (Ge 151). In addition, students shall successfully complete 45 units of 100-level or higher courses in a coherent field of specialization. This requirement may be satisfied by completion of a subject minor or through a set of courses chosen in consultation with and approved by the adviser and the option representative. A grade of C- or better is required for all course work that satisfies these requirements. Higher-level mathematics and physics courses are strongly encouraged. All candidates are expected to attend the planetary sciences seminar regularly. Satisfaction of the oral presentation requirement includes at least one 30-minute presentation annually by the student in the planetary sciences seminar, starting in the second year. Typically, students will present on their research work each year.

GPS Subject Minor
A student may, with the approval of the Division of Geological and Planetary Sciences, elect a minor in any one of the major subjects listed above. Such a subject minor will include at least 45 units in courses at the 100 level or higher. Normally, a member of the division faculty affiliated with the minor will participate in the student's oral thesis defense.

HISTORY (H)

The program for a subject minor in history must be approved by the executive officer for the humanities before the admission to candidacy. In addition to meeting general Institute requirements, the student must complete satisfactorily, with a grade of C or better, 45 units in advanced courses in history.

HISTORY AND PHILOSOPHY OF SCIENCE (HPS)

Graduate students in science, mathematics, or engineering may take a minor in history and philosophy of science (HPS). The graduate minor is devoted to the study of the historical evolution and philosophical underpinnings of the physical and biological sciences. Historical work in the minor includes the origins of experimental practice, the social and institutional contexts of science, the origins and applications of quantitative methods, specific developments since antiquity in physics, biology, and chemistry, as well as biographical and comparative studies. Philosophical research deals with issues in causation, explanation, scientific inference, the foundations of probability and decision theory, philosophy of mind and psychology, philosophy of neuroscience, and scientific fraud and misconduct.

The minor thus fosters the acquisition of broad knowledge about the scientific enterprise and related foundational problems, as well as more detailed analysis of the progress of and philosophical problems in particular branches of science. It is a valuable supplement to a technical degree since it helps equip students to understand the nature of scientific progress and to grapple with the conceptual basis of science and its wider ramifications. Students who successfully complete the HPS minor will be recognized with official credit for the achievement on their transcripts.

Requirements

Graduate students who take an HPS minor are expected to complete Hum/H/HPS 10, HPS 102 ab, HPS/Pl 120, at least three units of HPS 103, and 18 units of additional work in HPS, to be completed by taking courses in HPS/H or HPS/Pl numbered 99 or higher. Students need not complete the requirements for the minor within the first two years of graduate study.

INFORMATION AND DATA SCIENCE (IDS)

IDS Subject Minor

A subject minor in Information and Data Science (IDS) may be elected by graduate students who are pursuing PhD degrees in any option. The IDS graduate minor is designed for students who wish to broaden their expertise and get a solid background in the following areas: Mathematics of Data Science, Machine Learning, Statistical Data Analysis, and Information Theory.

To receive the IDS graduate minor, students must satisfy the following requirements:

1. Linear Algebra: ACM/IDS 104 or CMS/ACM/IDS 107
2. Probability: ACM/EE/IDS 116 or CMS 117
3. Statistics: IDS/ACM/CS 157 or ACM 118
4. Machine Learning: CMS/CS/CNS/EE/IDS 155 or CS/CNS/EE 156a
5. One course from the following list: Hum/Pl 45, CMS/ACM/EE 122, Ma/ACM/IDS 140 ab, CS/IDS 150 ab, ACM/EE/IDS 170, ACM/IDS 216, ACM/EE/IDS 217, Ec/ACM/CS 112, IDS/Ec/PS

126, ACM/IDS 154, IDS/ACM/CS 158, CS/CNS/EE/IDS 159, CS/CNS/EE/IDS 165, CS/IDS 121, EE/Ma/CS 126 ab, EE/Ma/CS/IDS 136, CMS/CS/IDS 139, CS/IDS 172, CS/EE/IDS 143, CMS/CS/Ec/IDS 144, EE/CS/IDS 160, EE/CS 161, CS/IDS 162, CS/EE/IDS 166, EE/CS/IDS 167, CS/IDS 178.

Note that all these courses have prerequisites that the student may need to take, depending on the student's background. The prerequisites can be satisfied with equivalent courses with approval from the instructor.

All courses used for fulfilling the IDS graduate minor requirements must be taken on a graded basis and students must obtain a grade of B or higher on all courses. Courses that are used to satisfy the minor requirements cannot be used to satisfy the requirements in the major options.

MATERIALS SCIENCE (MS)

Aims and Scope of the Graduate Program

The graduate program is designed to give students an understanding of general phenomena in synthesis–structure–property relationships in all materials, plus a detailed understanding of phenomena for at least one broad class of materials such as: physical materials science (solid state physics, quantum mechanics); mechanical materials science (micromechanics, continuum mechanics); soft materials (polymer chemistry/physics, chemical bonding); or oxide materials science (mineralogy/mineral physics). After completing the Ph.D. program, students have pursued careers in teaching and research at colleges and universities, in research for government and industry, in the operation and control of manufacturing processes, and in management and development positions in the materials industry.

Students may enter the graduate program in materials science with undergraduate preparation in physics, chemistry, engineering, or materials science. Students interested in terminating their graduate study at the master's level are not normally admitted. Students in the Ph.D. program are required to complete a set of core courses, pass an oral candidacy examination, complete a thesis describing original research in materials science or a related field, and publicly defend their thesis work.

MS Preparation for the Graduate Program

Students who have not specialized in materials science as undergraduates, as well as those who have, may be admitted for graduate study. As preparation for advanced study and research, entering graduate students are expected to have a thorough background in undergraduate mathematics, physics, and engineering. An outstanding four-year undergraduate program in mathematics and sciences is also a suitable background. The qualifications of each applicant will be considered individually, and, after being enrolled, the student will arrange their course of study and research in consultation with members of the faculty and the materials science option

representative.

MS Master's Degree

The degree of Master of Science in materials science is only awarded to students who do not already have an M.S. degree in Materials Science. The degree will be awarded upon request by students who have fulfilled the requirements. Only in exceptional cases is there admission to the M.S. program as the final degree objective.

Each student is assigned to a member of the faculty who will serve as the student's adviser. The adviser and option representative for materials science will approve the student's course of study. Study for the degree of Master of Science in materials science will ordinarily require at least three terms of courses. The courses shall be chosen from the list of core courses below, although 9 units of research (MS 200 or equivalent) may be substituted for 9 units of lecture or laboratory courses. Completion of 111 units of these courses within two years with no grade less than a C constitutes the academic requirements for the M.S. degree.

Graduate Coursework

1. Materials Science Core – 27 units
    a. MS 131, MS 132, MS 133
2. Thermodynamics – 27 units
    a. APh/MS/ME 105 abc or (ChE/Ch 164, ChE/Ch 165 + APh/MS/ME 105 c)
3. General Electives – 36 units
   Students are required to take at least 9 units on a) Specific Materials and at least 9 units on b) Fundamentals of Materials Behavior.
    a. Specific Materials
        i. Choose from: APh 114 abc, Ch 120, Ch 121 ab, Ch/ChE 147, ChE/Ch/MS 113, ChE/Ch 148, Ge 114 ab, ME/MS/Ae/AM 224, MS/APh 162
    b. Fundamentals of Materials Behavior
        i. Choose from: Ae/Ge/ME 160 ab, Ae/AM/MS/ME 213, APh/Ph/MS 152, APh/Ph/Ae/MS 153, Ch 117, Ch 125 ab, GE 214, ME/MS/AM 221, MS/ME/MedE 116, MS 121, MS/APh 122, MS 125, MS 142, MS/APh 141, MS/APh 171, MS/APh 256, MS/ME 161, MS/ME 166, Ph 125 ab
4. Mathematics – 18 units
    a. Choose from: ACM/IDS 104, ACM 100 ab, ACM/IDS 101 ab, ACM/EE 106 ab, CMS/ACM/IDS 107, MS/APh 141, Ph 129 ab
5. Materials Research Lecture Seminar Series – 3 units
    a. MS 110 abc

MS Degree of Doctor of Philosophy

The doctoral program in materials science consists of a series of preparatory classes, followed by an oral candidacy exam, a written thesis, and a final oral thesis defense. The goals of this program are to develop excellence in a chosen field of specialization; to develop tools with which to assess problems outside the student's field of specialization; to develop sufficient strength in the physical sciences for self-education beyond formal training; and to cultivate the motivation and foresight to become a productive and influential leader. As such, the graduate program in materials science is designed to be a doctoral program and students are only admitted into the doctoral program. There is no separate master's program in materials science.

The Ph.D. degree in materials science is focused on research. Study and research programs for the Ph.D. degree are individually planned to fit the interests and background of the student. A comprehensive research project resulting in an original contribution to the field documented by a dissertation is required.

Residency

A minimum of three academic years in residence as a graduate student are required by the Institute, and two or more additional years are usually needed for preparation of the thesis.

Language Requirement

There is no language requirement for the Ph.D. degree.

Minor

No minor is required for the Ph.D. degree. Students are, however, encouraged to take advanced courses appropriate to their particular interests.

Advising and Thesis Supervision

An interim adviser is appointed for each student upon admission to a graduate degree in materials science (typically the materials science option representative). The interim adviser will serve as the primary mentor until the student finds a research adviser. In the first year (no later than the third term), each student must choose a research adviser who will have primary responsibility for supervising the student's course program and research. The important adviser–advisee relationship requires effort from both parties, and some general expectations are outlined earlier in this section of the catalog. In consultation with their research adviser, the student should then form a Ph.D. Thesis Advisory Committee. This four-member committee should include: (i) the student's adviser, and (ii) at least three members of the Caltech professorial faculty. The research adviser and the Thesis Advisory Committee provide the majority of mentoring to the student, offering advice on research, progress toward the Ph.D., future careers, and other aspects of life in graduate school and as a professional scientist.

Requirements for Candidacy for the Ph.D. Degree
To be recommended for candidacy for the Ph.D. degree in Materials Science, the student must, in addition to meeting the general Institute requirements, do the following:

1. *Courses.* To continue in the graduate program, the student must maintain a B– average for each term. Advancement to candidacy requires the successful completion of the program listed under "Core Courses" above. Alternatively, if the student has taken equivalent courses elsewhere, they may prove competency to the instructor of the equivalent course at the Institute and request a waiver of the required course. With the Core Course requirements 1-5, students must complete a minimum of 111 units of courses, numbered 100 or above, before presenting themselves for Ph.D. candidacy. The coursework towards the Ph.D. degree in materials science is typically completed within the first two years of residency at Caltech.
    a. All courses must be passed with a grade of at least a C, except for courses taken on a pass/fail basis.
    b. Students must complete the degree progress report online.
    c. Alternate Subjects or Areas
        i. Students entering the program with advanced preparation may choose either to substitute more advanced courses in the topical areas shown or demonstrate competency to the course instructor.
        ii. Students may petition the materials science option representative to accept alternative subjects or areas, but such petitions must be submitted before the student registers for the courses.
2. *Oral Candidacy Examination.* This examination should be taken no later than the end of the student's second year of residence. The student's research adviser must be on the examining committee, but cannot serve as chair of the committee. The examination is based on the student's coursework, and how it is related to the student's planned research area. The student will be expected to deliver a half-hour oral presentation describing research to-date and will answer questions related to this work. This portion of the examination will be followed by more open-ended questions to test general proficiency in materials science. Students who fail the oral examination on their first attempt will be given additional guidelines for further study and an opportunity to retake the examination a second and final time if the committee so recommends. Students who fail the oral examination a second time cannot continue with doctoral studies leading to the Ph.D. Upon recommendation of the examining committee, however, a student may be granted a terminal master's degree. The approval of the materials science option representative is necessary for registration beyond the third year of graduate residence without successfully completing the candidacy exam.

3. *Research Competence.* The student must have a doctoral research adviser, and must have completed at least 18 units of MS 200. Students who fulfill the requirements above will be recommended for candidacy to the doctoral program and a master's degree (if applicable) in materials science.

Ph.D. Thesis Requirements
The candidate is to provide a draft copy of the completed thesis to the members of the examining committee (typically the same as the Thesis Advisory Committee) at least two weeks before the final oral examination. The date of the examination and the composition of the examining committee will not be approved by the dean of graduate studies until the thesis is submitted in completed form, i.e., ready for review by the dean, the members of the thesis committee, and the Graduate Office proofreader. Registration is required for the term in which the thesis defense is undertaken, but is not normally allowed beyond the last date of the term. For more information, please see the section entitled "Information for Graduate Students" in the *Caltech Catalog*.

Ph.D. Final Examination
The candidate is required to take a final oral examination covering the doctoral thesis and its significance in and relation to materials science. It will consist of a public thesis seminar and an associated oral examination on the thesis and related fields. The examining committee must consist of the student's adviser and three members of the Caltech professorial faculty. The chair of the examining committee must be a Caltech professorial faculty member distinct from the adviser. This examination will be held at least two weeks after the doctoral thesis has been presented in its final form, and prior to its approval.

Registration beyond the Sixth Year of Graduate Residence
The annual approval of the student's Thesis Advisory Committee or option representative is necessary for registration beyond the eighteenth academic term of graduate residence at Caltech. A petition to continue work toward the Ph.D degree must also be approved by the dean of graduate studies.

MS Subject Minor
Graduate students majoring in another option at the Institute may elect a subject minor in materials science. They must obtain approval from the materials science option representative for a course of study containing at least 45 units of advanced courses with a grade of C or higher. Normally a member of the materials science faculty will participate in the candidacy examination in the student's major department.

- Students cannot use courses required by their major option in fulfillment of this requirement.
- Students interested in a minor must receive prior approval from the option representative in materials science, who will review

and approve the proposed course of study.
- It is recommended that this course of study include advanced courses spanning different subfields of materials science.

MATHEMATICS AND MINOR (MA)

Aims and Scope of the Graduate Program
The principal aim of the graduate program is to develop the student's ability to do original research in mathematics. Independent and critical thinking is fostered by direct contact with faculty members. (Read more about the current research interests of the faculty.) Faculty advisers help students plan their programs of study leading to a Ph.D. in mathematics. Entering students are advised by the graduate option representative, who assists them in selecting appropriate courses, depending upon their previous studies.

Ma Master's Degree
Entering graduate students are admitted directly to the Ph.D. program, since the Institute does not offer a regular program in mathematics leading to the master's degree. A master's degree may be awarded in exceptional circumstances either as a terminal degree or preliminary to the Ph.D. Sufficiently advanced undergraduates may be admitted to graduate standing to pursue a master's degree simultaneously with the bachelor's program.

The recipient of a master's degree will be expected to take 135 units in advanced mathematics (numbered 110 and higher). Unless the student has placed out of some of them, these must include Math 110, 120, and 151 (the basic courses in analysis, algebra, and geometry) and at least two terms of discrete mathematics. Reading and/or research courses may only be included in this 135 units if approved by the executive officer for mathematics.

The general Institute requirements specify that the recipient of a master's degree must have taken at least 135 units of graduate work as a graduate student at the Institute, including at least 81 units of advanced graduate work in mathematics. This advanced work is interpreted as work with a course number greater than 109 and may include a master's thesis.

Ma Degree of Doctor of Philosophy Course Program
The graduate courses are listed in section five. The three core course series—Ma 110 abc in analysis, Ma 120 abc in algebra, and Ma 151 abc in geometry and topology—are required of all graduate students. Students are expected to complete each of the core course series during the first year of study, unless they complete the corresponding qualifying exam upon entrance to the program (see section on qualifying exams). In addition, students are required to complete nine quarters of other advanced mathematics courses Ma 111 and above, at least two of which are in discrete mathematics: combinatorics, complexity, and computability, or logic and set theory. Unless these nine course quarters are given pass/fail only, they must be taken for grades. Reading and research do not normally qualify to meet these

requirements. Under special circumstances (e.g., finishing the degree in three years), exceptions to these requirements may be considered by the graduate option representative. Beginning no later than the second year, students will be expected to begin independent research work and will be strongly encouraged to participate in seminars.

Qualifying Examinations
Qualifying examinations in the three core areas—analysis, algebra, and geometry/topology—emphasize mastery of the basic concepts and theorems and the ability to apply them to specific cases. Students are required to take and pass two of the three examinations, and for the third not taken, students must earn a B or better in all three terms of the corresponding course series. The exams are offered at the beginning of the Fall term and end of the spring term each academic year, with exceptional offerings made at other times of the year if needed and approved by the graduate option representative. The examinations must be attempted by the end of the spring term during the first year of study, and completed by the end of the first academic year. Entering students are permitted to take one or more qualifying examinations at the beginning of the fall term of their first academic year. If completed successfully, the student may drop the corresponding core course and will be excused from the remainder of the corresponding core requirement. Special exceptions or extensions to the qualifying examination timeline may be considered by the graduate option representative with support from the primary research adviser.

Teaching Requirements
Teaching is an integral part of the mathematics graduate education. It is expected that students serve as teaching assistants in each term courses are offered unless alternative arrangements have been made with the option and approved by the executive officer.

Summer Study
Although there are no courses given in the summer, graduate students are expected to carry out studies and research in their chosen area of mathematics. In the summer after the first year, they will work under the guidance of a faculty member to investigate a possible area for their thesis research.

Thesis Advising and Tracking Committee
It is expected that by the fall quarter of the second year, students will find a member of the faculty who agrees to serve as their thesis adviser. The formal change of adviser process should be complete by the end of the second academic year.

The progress of all continuing students is assessed by the faculty each fall, and students will consult with their advisers about their progress and planning of their studies and research. Students receive help and advice not only from their thesis adviser and other faculty mentors, but also whenever needed from the graduate option representative and the executive officer. (See also the section with guidelines for graduate student advising.) In addition to the primary

thesis adviser, each student will have a candidacy committee, Thesis Advisory Committee (TAC), and final defense committee. In most cases, the members of all of these committees are the same, but the student has the right to change the members. The student in consultation with their adviser will arrange the formation of the committee, which will have at least four members and meet the requirements listed in the subsection Graduate Policies and Procedure entitled 'Degree of Doctor of Philosophy.' At least two of the committee members should be members of the mathematics professorial faculty and the chair of the committees must be a professorial faculty who is not the primary research adviser.

Admission to Candidacy
Before the end of their third year, students are expected to finish the process of applying for admission to candidacy for the Ph.D. degree. This formal step requires completion of the qualifying examinations, core courses, and advanced courses, as well as a satisfactory oral presentation to a committee of faculty members. The presentation will describe both the general area of the student's proposed thesis research and the specific problem or problems to be addressed. The candidacy meeting should be complete by the beginning of the fourth year of study. It normally takes place during the spring term of the third year. In some cases, during the summer term of the third year, but scheduling must be done by the end of the spring term. Special exceptions or extensions to the admission to candidacy timeline may be considered by the graduate option representative with support from the primary research adviser.

Thesis Advisory Committee Meetings
The Thesis Advisory Committee (TAC) will track the student's progress through annual meetings between the candidacy exam and final defense. It is the responsibility of the student to convene the TAC during the fourth and fifth year of study. The fourth-year meeting should take place no later than the end of the winter term of the fourth year. The fifth-year meeting should take place no later than the end of the fall term of the fifth year.

Thesis and Final Examination
At least two weeks prior to the final thesis defense, candidates for the degree of Doctor of Philosophy must deliver copies of their theses to their advisers, to the Graduate Office, and to the members of the committee that will conduct the final oral examination on the thesis. The examination must be held at least three weeks before the date on which the degree will be conferred and at least two weeks after the delivery of the copies of the thesis.

Ma Subject Minor
Students majoring in other fields may take a subject minor in mathematics. Minor programs must include 54 units of advanced work approved by a representative of the mathematics department, who will ensure that the work represents a concentrated study in one or more of the main fields of mathematics. A special oral examination in the

subject minor will be given soon after completion of the minor program.

MECHANICAL ENGINEERING (ME)

Aims and Scope of the Graduate Program

Mechanical engineering (ME) research and study are offered through the Department of Mechanical and Civil Engineering (MCE). The degrees of Doctor of Philosophy (Ph.D.) and Master of Science (M.S.) are offered. In general, students who intend to work full-time toward the Ph.D. degree as a final degree objective are admitted to the Mechanical Engineering Graduate Program. The M.S. degree is typically only awarded to students who pursue the Ph.D. degree in mechanical engineering at Caltech and who do not already have an M.S. degree in mechanical engineering.

The aim of the graduate program in mechanical engineering at Caltech is to prepare students for research and professional practice in an era of rapidly advancing interdisciplinary technology. The program combines individual depth of experience and competence in a particular chosen major specialty, with a strong background in the basic and engineering sciences. It strives to develop professional independence, creativity, leadership, and the capacity for continuing professional and intellectual growth.

ME Preparation for the Graduate Program

Entering graduate students are expected to have a thorough background in undergraduate mathematics, physics, and engineering. While a strong undergraduate program in mechanical engineering should provide a suitable preparation, students who have not specialized in mechanical engineering as undergraduates may also be admitted for graduate study. For example, an outstanding four-year undergraduate program in mathematics and sciences may provide a suitable background as well. The qualifications of each applicant will be considered individually, and after being enrolled, the student will arrange their program in consultation with a member of the faculty.

ME Master's Degree

The degree of Master of Science in mechanical engineering is only awarded to students who do not already have an M.S. degree in mechanical engineering. The degree will be awarded upon request by students who have fulfilled the requirements. Only in exceptional cases is there admission to the M.S. program as the final degree objective.

A minimum of 138 units of courses numbered 100 or above, which meet the required master's program listed below, must be passed with a grade of at least C for completion of the master's degree in mechanical engineering. All units must be taken for grades, except for courses offered only on a pass/fail basis. The M.S. degree in mechanical engineering is typically completed within the first two years of residency at Caltech.

Each student's program must be approved by the adviser and option representative in mechanical and civil engineering before registering for the course.

Required Master's Program

1. Graduate mechanical engineering core (54 units). These units should provide a solid base for the student's engineering interest. The courses should be selected from the Core ME subjects listed under the Degree of Doctor of Philosophy Description and Requirements section.
2. Mathematics, engineering, and research electives (54 units). Courses may be taken in Ae, AM, ACM, ME, MedE, MS, EE, ESE, APh, CDS, CS, ChE, and CNS, except seminar courses. Students are encouraged to take research units, ME 300, up to a maximum of 27.
3. Free electives (27 units). Any course with a number of 100 or greater may be selected, except that research units and seminar courses can not be included.
4. Graduate Engineering Seminar, AM/CE/ME 150 abc (3 units).

ME Degree of Doctor of Philosophy

The Ph.D. degree in mechanical engineering is focused on research. Study and research programs for the Ph.D. degree are individually planned to fit the interests and background of the student. A comprehensive research project resulting in an original contribution to the field documented by a dissertation is required. A minimum of three academic years in residence as a graduate student are required by the Institute, and two or more additional years are usually needed for the preparation of the thesis.

Advising and Thesis Supervision

An interim adviser is appointed for each student upon admission to a graduate degree in mechanical engineering. The interim adviser will serve as the primary mentor until the student finds a research adviser. It is the responsibility of the student to find an academic and research adviser within three terms of graduate residence at Caltech. In consultation with the adviser, the student must form a Ph.D. Thesis Advisory Committee within four terms of graduate residence at Caltech. This committee shall consist of at least three members of the Caltech professorial faculty, with at least two members from the faculty in mechanical and civil engineering. The committee shall meet as requested by the student. Further, the committee shall meet annually to review progress and to approve the registration of the student beyond the fifth year of graduate residence at Caltech.

The adviser and the Thesis Advisory Committee provide the majority of mentoring to the student. In addition, the option representative and other members of the faculty are always available to provide advice and mentoring on any aspect of research, progress toward the Ph.D., future careers, and other aspects of life in graduate school and as a professional scientist.

Admission to Candidacy
To be recommended for candidacy for the Ph.D. degree in mechanical engineering, the student must, in addition to meeting the general Institute requirements, do the following:

- Obtain the agreement of a professorial faculty member to serve as the students academic and research adviser before the end of the third term of graduate residence at Caltech. In consultation with the adviser, the student must form a Ph.D. Thesis Advisory Committee before the end of the fourth term. This committee shall consist of at least three members of the Caltech professorial faculty, with at least two members from the faculty in mechanical and civil engineering.
- Pass both subject and research components of the oral candidacy examination before the end of the eighth term of graduate academic residence at Caltech. If the student has chosen a subject minor, an examination on the subject of that program may be included at the request of the discipline offering the subject minor.
- Complete a minimum of 195 units of courses numbered 101 or above, that fulfill the required Ph.D. program listed below. All units must be taken for grades and passed with a grade of at least a C, except for courses offered only on a pass/fail basis. The coursework towards the Ph.D. degree in mechanical engineering is typically completed within the first three years of residency at Caltech.

The faculty will evaluate the student's research progress, class performance, adviser's input, and oral candidacy exam results to determine whether a student will be admitted to or be able to maintain candidacy for the Ph.D. degree.

Required Ph.D. Program

1. *ME Core Subjects* (54 units): Coursework in core mechanical engineering subjects selected from the courses below. Pass with a grade of at least C, 36 units must be in a single track (Depth requirement). An additional 18 units must be from the courses below but can be in any track, including the chosen Depth track.

   Tracks:
   Thermal-fluid sciences: Ae/APh/CE/ME 101 abc, APh/MS/ME 105 abc, APh/Ph/MS 152, APh/Ph/Ae/MS 153, Ae/ME 118, ME 119, Ae/ME 120, Ph 127 ab, ChE/Ch 164, ChE/Ch 165.
   Mechanics of solids, structures, and materials: Ae/AM/CE/ME 102 abc, Ae/APh 104 abc, AM/CE 151, Ae/Ge/ME 160 ab, Ae/CE 165 ab, ME/CE/Ge 174, Ae/AM/MS/ME 213, Ae/AM/CE/ME 214, Ae 220, Ae/CE 221, ME/MS/AM 221, Ae/AM/ME 223, AM/CE/ME 252, ME/Ge/Ae 266 ab.
   Robotics, Controls and Dynamics: ME/CS/EE 129, CDS 131, ME/CS/EE 133 ab, ME/CS/EE 134, CDS 141, CMS/CS/CNS/EE/IDS 155, ME/CS/EE 169, CDS 212, CDS 231,

CDS 232, CDS 233, ME/CDS/EE 234 ab, ME/CDS 235 ab.

2. *Electives or Minor* (54 units): Additional engineering or science courses with course number 101 or above, except seminar or research courses. ACM 100 can be taken as an elective with the advisor's approval. Pass with a grade of at least C, courses that are approved by the Thesis Advisory Committee. These courses are intended to provide further depth and incorporate breadth. These units can be used to satisfy a minor requirement in another option.
3. *Advanced mathematics or applied mathematics* (27 units): Pass with a grade of at least C, chosen in consultation with adviser from the following list: ACM 101 or higher, CDS 232, Ma 108 or higher, Ph 129. The requirement in mathematics is in addition to the requirements above.
4. *Graduate engineering seminar* (6 units): Six terms of AM/CE/ME 150 abc, within the 12 terms or 3 years in residence at Caltech.
5. *Research* (54 units): Successfully complete at least 54 units of research and demonstrate satisfactory research progress.

Registration Beyond the Sixth Year of Graduate Residence
The annual approval of the Ph.D. Thesis Advisory Committee is necessary for registration beyond the twenty-fourth academic term of graduate residence at Caltech.

Thesis and Final Examination
The thesis examination will be given after the thesis has been formally completed. This examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in the specialized field of research. The format of the examination can be chosen from the following two options, by the student, in consultation with the students research adviser: (i) a public seminar presented by the candidate, with an open question period, followed by a private examination by the Examining Committee or (ii) a private presentation to the Examining Committee followed by the examination, with a public seminar on another date. The Examining Committee shall consist of a minimum of four voting members, three of whom must be Caltech faculty; two members must be from MCE. The Thesis Defense Committee shall be chaired by a committee member who is an MCE Caltech professorial faculty member and not the student's adviser.

ME Subject Minor
A student majoring in another branch of engineering or another division of the Institute may, with the approval of the faculty in the Department of Mechanical and Civil Engineering and the faculty in the students major field, elect mechanical engineering as a subject minor. The program of courses must differ markedly from the major subject of study or research, and must consist of at least 54 units of advanced courses (101 or above) approved by the faculty in mechanical and civil engineering.

MEDICAL ENGINEERING (MEDE)

Aims and Scope of the Graduate Program

The Andrew and Peggy Cherng Department of Medical Engineering offers a program of study that leads to the Ph.D. The medical engineering option at Caltech is designed for students with an engineering background who are interested in applications of micro-/nanoscale science and technology in medicine, which forms the core of Caltech's multidisciplinary medical engineering. The program's goal is to close the gap between engineering and medicine. Our medical engineering research and education leverage Caltech's strengths in engineering, applied science, and other fundamental fields, to apply emerging technological advances to medicine, and to create innovative diagnostic, monitoring, and therapeutic systems. Our major areas of research include micro/nano medical technologies and devices, medical nanoelectronics, biomedical materials and biomechanics, fluidics and bioinspired design, and medical imaging and sensing.

The Degree of Doctor of Philosophy offers two tracks: MedE only and Medical and Electrical Engineering (Med-EE). The Med-EE track is offered jointly by both departments of Medical Engineering and Electrical Engineering (see EE Section). The single degree to be shown on the diploma is "Ph.D. in Medical and Electrical Engineering".

MedE Master's Degree

Students are not normally admitted to work towards the M.S. degree. However, the M.S. degree may be awarded to a student along the way toward a Ph.D. degree, provided Institute and Option requirements are met. The Option requirements for the MS degree are the same as those for the Ph.D. degree except that the MS degree does not require research units, qualifying exam, candidacy exam, and thesis defense. In general, the degree is not conferred before the end of the first year of residence. Currently, there is not a Med-EE track M.S. degree so in order for the Med-EE students to earn their M.S. degree they have to fulfill the MedE program requirements.

MedE Degree of Doctor of Philosophy

Admission to Candidacy

To be recommended for candidacy for the Ph.D. program in medical engineering, each student must complete a total of 135 units (waived courses do not reduce this requirement) and complete all the following requirements:

- Complete 27 units of advanced math courses (i.e., 100 level or above) or ACM 100ab, as arranged with their adviser. Math courses that are recommended include, but are not limited to: ACM 100ab, ACM/IDS 101, ACM/IDS 104, ACM 105, ACM 106abc, ACM 201ab, ACM 210ab, ACM/EE/CMS 116, Ma 125, and Ma 112ab.

- Complete the three-term seminar sequence, MedE 100abc (1 unit), with a pass grade.
- Complete MedE 101a (9 units)
- Complete a 9-unit MedE Course. The 9-unit MedE course can be double-counted towards the additional 42 units.
    - Biodevices: BE/EE/MedE 189ab (12 and 9 units) , EE/MedE 185 (9 units) , EE/MedE 187 (9 units), MedE 201 (9 units), MedE 202 (9 units), or MedE/EE 204 (9 units).
    - Biomechanics/Fluidics: MedE/BE/Ae 243 (9 units), ChE/BE/MedE 112 (9 units) or ChE103b (9 units).
    - Biomedical Optics: MedE/EE 168abc (9 units each).
    - Medical Imaging: MedE/EE 268 (9 units).
- Complete EE 111 (9 units).
- Complete at least 27 units of MedE 291 individual research.
- Complete minimally an additional 42 units of advanced courses (100 level or higher) in any of the following 8 topical areas as arranged with the student's adviser. Research units cannot be counted towards the 42 units. Courses that are recommended but not limited to, include:
    - Biology and Physiology: BE 150, BE 151, BE/Bi 152, BE 159, Bi/Ch 110, Bi/Ch 113, Bi 122, Bi 129, Bi 145, Bi/CNS/NB 150, Bi/CNS 162, CNS/Bi/Ph/CS/NB 187.
    - Biomaterials, Biomechanics, and Bioinspired Design: Ae/BE 242, BE 141, BE 159, Ch/ChE 147, MS 115, MS/ME/MedE 116.
    - Biosensing: APh/EE 130, APh/EE 131, APh/EE 132, ChE/BE/MedE 112, EE/MedE 114ab, EE/MedE 115, EE 151, EE 161, MedE/EE/BE 168abc, MedE 201, MedE 202.
    - Fluid Mechanics: Ae/APh/CE/ME 101abc, Ae 160, Ae/BE 242, ChE/BE/MedE 112.
    - Fundamental and Mathematically Oriented Engineering: APh/EE 130 (EM), CDS 101, CDS 110, CDS 140, ChE 103abc, ChE/BE/MedE 188, EE 112, EE/Ma 126 ab, EE 151, EE/CS/IDS 160, EE/CS 161, MS 115, ME 115 ab, ME 118, ME 119ab.
    - Medical Photonics and Imaging: APh/EE 130, APh/EE 131, APh/EE 132, Bi/BE 177, Bi/BE 227, ChE 114, EE/MedE 115, EE 151, EE/APh 180, MedE/EE/BE 168abc, MedE 205, MedE/EE 268.
    - Medical Technologies and Devices: APh 109, APh 114abc, APh/EE 130, APh/EE 131, APh/EE 132, BE/EE/MedE 189 ab, ChE/BE/MedE 112, ChE 115, E/ME/MedE 106 ab, EE 112, EE/MedE 114 ab, EE/MedE 124, EE 151, EE/APh 180, EE/MedE 185, EE/MedE 187, MedE/EE/BE 168abc, MedE 201, MedE 202, MedE/EE 204, MedE 205, MedE/EE 268.
    - Solid Mechanics: Ae/AM/CE/ME 102abc, Ae 160, AM/ CE 151ab, MS/ME/MedE 116.
- Required courses must be taken for grades and passed with a grade of at least a C, except for courses offered only on a pass/fail.

- Pass an oral qualifying examination, arranged by the option, on three major subjects before the beginning of the second academic year. Any delay in taking the exam must be preapproved by the option representative. Each student should consult their adviser and/or the option representative to choose the three major subjects. The three subjects of the exam should include (1) Engineering math, Note: Students getting a B- or better for all 27 math units will be waived for "math subject" exam. (2) The major research topical area, and (3) Another related topical area. Students should take at least 27 units of advanced courses on each of the three exam subjects. Transferred credits can be counted toward the 27 units. If the student has a subject minor, examination on the minor subject may be included at the request of the discipline offering the minor and with the approval of the student's adviser. Note that the program is designed for the students to have a multidisciplinary background.
- Pass an oral candidacy examination on the subject of the Ph.D. research before the end of the third academic year of residency. The Ph.D. oral candidacy exam is conducted by a committee of a minimum of four members that is set up by the student and approved by the option representative. Three members must be Caltech professorial faculty affiliated with Medical Engineering. The fourth member may be a Caltech faculty member or an outside professional of similar standing. The committee must include the adviser, but another member of the committee must be selected as chair. The committee chair must be a Caltech professorial faculty member. This examination will be a test of the candidate's preparation and knowledge to conduct research in their specialized doctoral research area.

Thesis and Final Examination.
The Ph.D. final thesis defense exam is conducted by a committee of a minimum of four members that is set up by the student and approved by the option representative. Three members must be Caltech professional faculty affiliated with Medical Engineering. The fourth member may be a Caltech faculty member or an outside professional of similar standing. The committee must include the adviser, but another member of the committee must be selected as chair. The committee chair must be a Caltech professorial faculty member. This final examination will be given no less than two weeks after the doctoral thesis has been presented in final form, and before its approval. This examination must be taken at least four weeks before the commencement at which the degree is to be granted. This thesis examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in their specialized doctoral research area.

Med-EE Track Degree of Doctor of Philosophy
The track was established by Andrew and Peggy Cherng Department of Medical Engineering and the Department of Electrical Engineering at Caltech. The single degree to be shown on the diploma is "Ph.D. in Medical and Electrical Engineering".

Admission to candidacy.
To be recommended for candidacy for the Med-EE Ph.D. program, each student must do the following.

- **Complete a minimum of 156 units of courses** . The MedE requirement of 21 units of MedE courses plus the EE requirement of 135 units must be met. Cross-listed MedE/EE courses can be double counted.
  - MedE course requirements
    - Complete the three-term seminar sequence, MedE 100abc (1 unit), with a passing grade.
    - Complete MedE 101a (9 units)
    - Complete a 9-unit MedE course.
      - Biodevices: BE/EE/MedE 189ab (12 and 9 units), MedE 201 (9 units), MedE 202 (9 units), or MedE/EE 204 (9 units).
      - Biomechanics/Fluidics: MedE/BE/Ae 243 (9 units), ChE/BE/MedE 112 (9 units), or ChE 103b (9 units).
      - Biomedical Optics: MedE/EE 168abc (9 units each).
      - Medical Imaging: MedE/EE 268 (9 units).
    - All required courses must be taken for grades and passed with a grade no lower than C, except for those courses offered only for pass/fail.
  - EE course requirements
    - Complete 135 units total with no more than 30 units of pass/fail.
    - Complete 54 units of letter-graded EE courses numbered 100 or above towards the 135-unit requirement.
    - Complete 27 units of mathematics courses, with letter grade no lower than C. Many math-related courses can count towards the requirement after confirming with your advisor.
    - Complete 18 units of research in your field of interest directed by your advisor.
- **Pass the oral qualifying and oral candidacy exams** of the MedE department for students having chosen MedE as the home department. Please refer to the EE Section for the reciprocal requirement.

Thesis and Final Examination.
The Med-EE Ph.D. thesis must be related to both options. The final thesis defense exam is conducted by a committee that is set up by the student and approved by the option representative of the home department. The committee must be composed of 2 members from each option. The committee must include the advisor, but another member of the committee must be selected as chair. The committee chair must be a Caltech Professorial faculty member. This final examination will be given no less than two weeks after the doctoral thesis has been presented in final form, and before approval. This examination must be taken at least four weeks before the commencement at which the degree is to be granted. This thesis examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in their specialized doctoral research area.

MedE Subject Minor
A subject minor is not required, but recommended, for the Ph.D. degree in medical engineering. However, credits from the subject minor cannot be double-counted for the core program. Students may choose their original engineering disciplines as their minor subjects. Students are not allowed to choose medical engineering as a subject minor.

NEUROBIOLOGY (NB)

Aims and Scope of the Graduate Program
Neurobiology—the study of the nervous system—is a highly integrative science. The modern neurobiologist must be conversant with concepts from molecular biology, cell and developmental biology, systems neuroscience, animal behavior, and mathematical modeling. The aim of the graduate program is to expose each student to this breadth of the discipline. To accomplish this, we offer a first-year curriculum with requirements in specified areas, along with a core course that spans many subjects. Students enter neurobiology from many different disciplines, ranging from particle physics to physiology to psychology. Accordingly, each Ph.D. student is paired with a first-year adviser so the course selections can best complement the student's background. In later years, the student's focus is on original research in a chosen specialty. Our goal is that students will graduate with specific research accomplishments and the broad understanding required to chart their subsequent forays in brain science.

NB Admission
Applicants are expected to have studied college-level mathematics, physics, chemistry, and biology. They should also have experience in independent research. Coursework in neurobiology and experience in scientific computing are helpful, but not required. Whenever possible, applicants will be interviewed on campus before final admission decisions are made.

NB Master's Degree
The option does not admit students for work toward the master's degree. A terminal M.S. may be awarded in exceptional circumstances.

NB Degree of Doctor of Philosophy

First-year adviser
Each incoming student is paired with an academic adviser during the first year. This mentor will guide the student in course selection and other decisions, taking the student's background into account. Where possible, this adviser will not be one of the prospective rotation supervisors.

Rotations
First-year students carry out three laboratory rotations, each lasting one quarter. At least two of these should be with faculty participating in the option. By June 30 of the first year, students choose a Ph.D. adviser.

Formal Classes
Students take at least 6 quarter courses (54 units) as follows:

1. Bi/CNS/NB 164, Tools of Neurobiology
2. Bi 252, Responsible Conduct of Research
3. One course in molecular, cellular, developmental neurobiology
4. One course in circuits, systems, behavioral biology
5. One course in mathematical methods (depending on the student's background)
6. Two electives

For a list of courses in subject areas 3–5, see the option website. All courses must be taken for a grade unless only offered pass/fail.

Teaching
All students are to serve as teaching assistants for at least two terms.

Admission to Candidacy
To qualify for candidacy, the student must first demonstrate broad competence by passing each of the first-year courses with a grade of B or higher. Failure here can be remedied by successful second-year coursework. By June 30 of the second year, the student must also defend a thesis proposal in an oral exam before a qualifying exam committee of at least three faculty. This exam will also cover general knowledge in the relevant field. With special permission, the oral exam may be retaken once before the end of winter quarter of the third year. Students that do not advance to candidacy by the end of the third year may not continue in the program.

Thesis Advisory Committee
Once admitted to candidacy, the student chooses a Thesis Advisory Committee of at least three faculty. This committee serves as a source of advice independent of the Ph.D. adviser throughout the student's tenure. Each year, before the end of June, the student delivers a written progress report, followed by a meeting with the Thesis Advisory Committee.

Thesis Examination Committee
This committee should consist of a minimum of four voting members, three of whom must be Caltech faculty. The final oral examination covers principally the work of the thesis, and according to Institute regulations must be held at least three weeks before the degree is to be conferred.

PHYSICS (PH)

Aims and Scope of the Graduate Program
The physics option offers a program leading to the degree of Doctor of Philosophy. This program prepares students for careers in scientific research or research combined with teaching, and so its most important part is independent research. Courses are offered that give a broad treatment of both fundamental physics and specialized physics research topics. These are intended both to help a beginning graduate student prepare for research and to broaden an advanced student's knowledge of physics. Caltech research opportunities include elementary particle physics, nuclear physics, cosmic-ray, gamma-ray, and X-ray astronomy, submillimeter astronomy, condensed-matter physics, atomic/molecular/optical physics, quantum information, applied physics, gravitational physics, cosmology, astrophysics, mathematical physics, biophysics, and theoretical physics.

A Master of Science degree may be awarded upon completion of a program of courses. Students are not normally admitted to work toward the M.S. in physics unless they are also working toward a Ph.D.

Admission
The application submission deadline for physics is December 15. The admission process follows Institute regulations.

Ph Master's Degree
A Master of Science degree in physics will be awarded, upon request, to physics Ph.D. students who have completed the oral and written candidacy examinations. Alternatively, a master's degree will be awarded to any Caltech graduate student in good standing upon satisfactory completion of a program approved by the option representative that fulfills the following requirements:

Ph 125 abc	**27 units**
(If this course, or its equivalent, was taken as part of an undergraduate program, it may be replaced by 27 units of any quantum-mechanics–based course.)	
Physics electives	**81 units**
These must be selected from physics courses numbered 100 and above.	
Other electives	**27 units**
These must be graduate courses from any option at Caltech.	

Substitutions of other graduate courses in place of the above requirements must be approved by the option representative.

In exceptional cases, undergraduate students may receive concurrent B.S./M.S. degrees if the above requirements are met in addition to the relevant B.S. requirements, upon approval from the Physics Graduate Committee, the graduate admissions committee, and the physics executive officer. Such students must produce a detailed petition demonstrating accomplishments that would warrant normal admission to the physics graduate program.

Ph Degree of Doctor of Philosophy

In addition to the general Institute requirements for a Ph.D., the particular requirements for a doctorate in physics include admission to candidacy as described below, writing a thesis that describes the results of independent research, and passing a final oral examination based on this thesis and research. Physics graduate students may exercise the pass/fail option on any and all courses taken.

Advising structure and thesis supervision

An academic adviser is appointed for each student upon admission to the graduate program in physics. The academic adviser will serve as the primary mentor until the student finds a research adviser. Students will meet with their academic adviser to decide on their first-year course schedule, and are encouraged to continue these meetings quarterly until the student finds a research adviser. During the first year of study, students should consult with their academic adviser, the option representative, the executive officer, and/or individual faculty members to select a tentative research group. Once a research adviser is selected students may either replace the originally appointed academic adviser or maintain both a research adviser and academic adviser. At any time, a student may consult with the option representative concerning such matters as advising.

Students should consult with the executive officer to assemble their oral candidacy committee and Thesis Advisory Committee (TAC) by the end of their third year. The TAC is normally constituted from the candidacy examiners, but students may propose variations or

changes at any time to the option representative. The TAC chair is normally someone other than the research adviser. The TAC chair will typically also serve as the thesis defense chair, but changes may be made in consultation with the executive officer for physics and the option representative.

The candidacy committee will examine the student's knowledge of their chosen field and will consider the appropriateness and scope of the proposed thesis research during the oral candidacy exam. This exam represents the formal commitment of both student and adviser to a research program. After the oral candidacy exam, students will hold annual meetings with the TAC. The TAC will review the research progress and provide feedback and guidance towards completion of the degree.

The TAC, research, and/or academic advisers provide the majority of mentoring to the student. In addition, the option representative and other members of the faculty are always available to provide advice and mentoring on any aspect of research, progress toward the Ph.D., future careers, and other aspects of life in graduate school.

Basic Physics Requirement

Physics students must demonstrate proficiency in all areas of basic physics, including classical mechanics (including continuum mechanics), electricity and magnetism, quantum mechanics, statistical physics, optics, basic mathematical methods of physics, and the physical origin of everyday phenomena. A solid understanding of these fundamental areas of physics is considered essential and proficiency will be tested by two written candidacy examinations.

No specific course work is required for the basic physics requirement, but some students may benefit from taking several of the basic undergraduate courses, such as Ph 106, Ph 125, and Ph 127. A syllabus describing the exam contents will be available, and students are encouraged to study independently for the exams, rather than taking a heavy load of basic physics courses. In addition, the class Ph 201 will provide additional problem solving training that matches the basic physics requirement.

The written exams are typically offered in July and in October, and the two separate exams may be taken at different times. This flexible scheduling of the written exams allows students to prepare for the exams while simultaneously learning about research areas, either through advanced courses, reading courses, or participation in a research group. The exams can be attempted up to three times and must be successfully completed by the end of the second year of study.

Advanced Physics Requirement

In addition to demonstrating a proficiency in basic physics, students must also establish a broad understanding of modern physics through study in six graduate courses. The courses must be spread over at least three of the following four areas of advanced physics:

1. Physics of elementary particles and fields:
   Nuclear physics, high-energy physics, string theory
2. Quantum information and matter:
   Atomic/molecular/optical physics, condensed-matter physics, quantum information
3. Physics of the universe:
   Gravitational physics, astrophysics, cosmology
4. Interdisciplinary physics:
   e.g., Biophysics, applied physics, chemical physics, mathematical physics, experimental physics

Each area is meant to be covered by the equivalent of a one-term course, and a list of example courses for each of the areas can be found at the physics option website. Other courses may be substituted with permission of the physics option representative.

Oral Candidacy Exam

This exam is primarily a test of the candidate's suitability for research in their chosen field. The professor with whom the student plans to do research will be a member of the exam committee, and normally the student will have already begun research (Ph 172) on a definite topic with that professor. The examination will cover the student's research work and its relation to the general field of specialization. Before being allowed to take this exam, a student must have satisfied all the other requirements for admission to candidacy. The oral candidacy exam should ideally be completed by the Spring term of the third year, and no later than the Summer term of the third year (12th term) of graduate residence.

Admission to Candidacy

To be recommended for Ph.D. candidacy, a student must pass two terms of Physics Seminar (Ph 242), satisfy the Basic Physics Requirement by passing the written candidacy examinations, satisfy the Advanced Physics requirements, and pass the Oral Candidacy Examination. These requirements are designed to ensure that students have adequate preparation in the basic tools of physics, as well as a broad general knowledge of advanced physics.

Research Requirements

There are no specific research requirements, but in general a substantial effort is required to master the techniques in a given field and carry out a significant piece of original research. Students are strongly advised to start doing part-time research as soon as possible by taking reading and research units (Ph 171–172) in parallel with formal coursework.

Teaching Requirement

It is expected that each graduate student will, as part of the Ph.D. graduation requirements, serve as a teaching assistant for at least one term, an experience that most students find provides valuable experience for their future careers. Students are encouraged to fulfill this requirement within the first three years of residency.

Thesis and Final Examination
A final oral examination will be given not less than two weeks after the thesis has been presented in final form. This examination will cover the thesis topic and its relation to the general body of knowledge of physics. The candidate is responsible for completing the thesis early enough to allow the fulfillment of all division and Institute requirements, with due regard for possible scheduling conflicts.

Degree progress timeline
The following timeline is required for satisfactory degree progress:

1. Ph 242 should be taken by all students in their first year of graduate study.
2. The written candidacy exams should be attempted by the end of a student's first year of graduate residence, and be passed by the end of the second year.
3. The Advanced Physics requirement should be completed by the end of the second year of graduate residence, but may be extended into the third year depending on the availability of specific courses.
4. The oral candidacy exam must be completed by the end of the third year (12th term) of graduate residence.

The Minor
A minor is not required, but a student may elect to pursue a minor in another option.

Language Requirements
There are no language requirements for a Ph.D. in physics.

Ph Subject Minor
Students desiring a subject minor in physics should discuss their proposed program with the chair of the Physics Graduate Committee. Forty-five units from physics courses with numbers over 100 must be taken for the subject minor, excluding any specific courses in physics required for the student's major program. An oral exam may be required by the Physics Graduate Committee. This exam will include both academic topics and topics on current physics research areas.

QUANTUM SCIENCE AND ENGINEERING (QSE)

Aims and Scope
Quantum science and engineering (QSE) may be pursued as a subject minor by graduate students who are pursuing Ph.D. degrees in any option. The QSE minor is intended to supplement one of Caltech's graduate degrees and is designed for students who wish to broaden their knowledge of QSE beyond their major field of study. The QSE minor is also intended to recognize graduate students' interest in and dedication to QSE as demonstrated by the successful completion of a program of study in the field. Completion of the QSE minor program of study will be recognized on the Ph.D. diploma by the statement, "…and by additional studies constituting a minor in Quantum Science

and Engineering."

Requirements
To receive the QSE minor, graduate students must fulfill the following requirements:

- APh/Ph 138ab
- 18 units (two terms) from the following list: APh/EE 190abc, CS/Ph 120 , EE/APh 158, Ph 137ab, Ph/CS 219abc, Ph/APh 223ab, APh 150 (special topics class when topic is relevant to QSE, in consultation with the oversight committee), Ph177 (relevant QSE topic must be chosen in consultation with oversight committee). Other courses relevant to QSE can be included in consultation with the oversight committee.

All courses to be applied toward the QSE minor requirements must be taken on a graded basis unless only offered as pass/fail. Students must obtain a grade of B- or higher in all courses taken on grades and a pass in courses taken as pass/fail. At least 18 units of courses that are used to satisfy the QSE minor cannot be used to satisfy course requirements in the major options unless absolutely required by the option. Courses taken as part of the QSE minor are counted toward the total number of units required for the completion of the Ph.D. degree.

QSE Minor Administration
The QSE minor is administered by an oversight committee consisting of faculty members reporting to the chair of the engineering and applied science division. In consultation with their advisers and, if needed, with the QSE Oversight Committee, students formulate a program of approved courses individually tailored to each student's background and needs, with the objective that the student achieve a level of competence in specific subjects relevant to QSE. Students must petition the QSE Oversight Committee for approval of their program of study. Upon completion of the program of study, the QSE Oversight Committee will verify that the QSE minor requirements have been fulfilled.

SOCIAL AND DECISION NEUROSCIENCE (SDN)

Aims and Scope of the Graduate Program
The Caltech Ph.D. program in social and decision neuroscience (SDN) prepares students to do research on the neurocomputational basis of decision-making and social interactions. Research in this area requires training in computational modeling, statistical methods, systems neuroscience, neural measuring methods such as fMRI, EEG or single unit recordings, as well as adequate understanding of related methods and results from the social sciences. Students' career paths include faculty jobs in neuroscience, psychology or marketing; faculty jobs in economics, political science or finance programs; and industry positions in the technology, data science, finance, and

neurotechnology sectors.

SDN Master's Degree
Students are not admitted to work towards the master's degree. The master's degree might be awarded to an SDN student under exceptional circumstances. In order to be eligible for a master's degree, students must complete at least 54 units of the courses required for the Ph.D. with a passing grade, as well as a minimum of 81 additional units of graduate work.

Admission
The program seeks to recruit top students interested in the neurocomputational basis of decision-making and social interactions. Ideal applicants will have very strong quantitative backgrounds, regardless of their undergraduate major. Previous exposure to neuroscience, psychology or economics is useful but not required. Detailed information on admission requirements can be found at www.hss.caltech.edu/graduate-studies/social-and-decision-neuroscience-phd-program/admissions.

Course Requirements
Students are required to complete 81 units of graduate coursework related to social and decision neuroscience by the end of their second year, with a grade of B or higher in each class. The coursework must satisfy the following requirements. Students should take a minimum of 54 units during their first year and 27 units during their second year. First year coursework must include CNS/ Psy/Bi 102 ab (Brains, Minds, and Society) and two courses in statistics, econometrics or machine learning. Students are also required to take NB/Bi/CNS 150 (Introduction to Neuroscience), a graduate course in behavioral economics, and two additional upper-undergraduate or graduate courses (i.e., numbered 100 or higher) in economics, political science or finance.

Lab Rotations
Students are required to complete three quarters of lab rotations during their first year. These rotations should include work in two different labs, for a minimum of one quarter each. Lab rotation plans need to be approved by the option representative by the end of the second week of the fall quarter. Students must sign-up for 18 units of CNS 280 (Research in Computation and Neural Systems) or SS 300 (Research in the Social Science) for each quarter of lab rotations. Students are expected to become full members of a research group by the end of the spring quarter of their first year. The faculty member leading that lab becomes the student's main adviser.

General Knowledge Exam
Students are required to take a written General Knowledge Exam in Social and Decision Neuroscience. The exam is offered during Spring quarter of the second year and students must pass it with a grade of at least 80%. A list of topics and references associated with the exam can be obtained from the option representative.

Other Requirements
Students must satisfy the following additional requirements.

1. They must enroll in Psy 283abc (Graduate Proseminar in Social and Decision Neuroscience) every quarter, from their first to their last quarter in residence. This weekly seminar provides training in academic skills such as writing, presenting, reviewing, and career strategy, as well as breadth of knowledge in Social and Decision Neuroscience.
2. First year students must enroll for SS/Psy/CNS 285 each quarter it is offered during the academic year.
3. Students must attend four social science seminars in economics, finance or political science every quarter, from their first to their last quarter in residence.
4. Students are also required to complete Bi 252 (Responsible Conduct of Research) during their first year.
5. Students must attend a conference and submit a grant proposal during their second year.
6. Starting their second year, students are expected to TA a minimum of three quarters during their graduate career.
7. Starting the third year, students must present a poster or give a talk at a conference every academic year.
8. Students must submit yearly progress reports to the SDN option representative by the last day of classes of the Spring quarter, starting on their first year. A template for the report can be obtained from the option representative. These reports will be reviewed by the entire SDN faculty and granted one of three outcomes: approval, conditional approval, or program termination. Students may receive at most one conditional approval of their yearly report during their time in the Ph.D. program.

Candidacy Requirement
Students must form a thesis committee and defend their thesis proposal to the committee. Students must pass this candidacy exam by the last day of classes of their third year. A thesis committee must have four members subject to the following constraints: at least one should be a neuroscience faculty member, at least one should be a non-neuro social science faculty member, and there should be at most one faculty member from another institution. The main adviser cannot serve as the chair of the thesis committee.

Thesis and Final Examination
The candidate is expected to complete and successfully defend their thesis by the last day of classes of the spring quarter of their fifth year. Extensions to an additional sixth year will be considered only at the candidacy exam stage and, if necessary, for the proposed research plan. The time of the defense should be determined in consultation with the main adviser, the thesis committee and, if necessary, the option representative. Students must submit a written copy of their dissertation to the the-sis committee at least two weeks prior to the

thesis defense date.

SOCIAL SCIENCE (SS)

Aims and Scope of the Graduate Program
The Caltech Ph.D. program in social science prepares students for a research career in economics and political science. It is designed to produce scholars who are well grounded in the theoretical perspectives, the quantitative techniques, and the experimental methods of economics and political science.

SS Master's Degree
Students who are enrolled in the Social Science Ph.D. program may earn a M.S. degree after successful completion of 36 units of course work, completed with a grade of B or better in each class, in addition to completing the coursework required for the first year of the Ph.D. program.

Admission
Detailed information on admission requirements can be found at hss.caltech.edu/academics/graduate-studies/social-sciences-phd-program/admissions.

Course Program
First year. The first-year curriculum consists of the following three-quarter course sequences: Political Theory (SS 202abc); Foundations of Economics (SS 205abc) and Econometrics (SS 222abc). Each class must be completed with a grade of B or better. During the spring term, students may enroll in SS 201c or suitable alternative graduate courses in lieu of sequence classes. In addition, students must register for SS/Psy/CNS 285 each quarter it is offered during the academic year, and in each term enroll in an SS 300 course.

At the end of the first year, the faculty will review the overall class performance of each first-year student and assess the student's ability for clear self-expression in both oral and written English. A positive assessment of class performance is required for a student to remain in good standing in the program. If class performance is judged unsatisfactory by the faculty, they may terminate the student from the program.

Before the start of the second year, students are required to take a written preliminary examination, which has three components, each corresponding to one of the first-year course sequences (SS 202, SS 205, and SS 222). A student who achieves a grade of A- or higher in all three courses of a sequence will be exempted from taking the corresponding component of the exam. The grades given are Honors, Pass, and Fail. Students must achieve at least a Pass in all three components. Students who fail a component may be given the opportunity to retake it before the start of the fall term by the faculty. The Social Science faculty will then review the student's performance on the exam(s), and progress, to date. If it is not satisfactory, they may terminate the student from the program by the beginning of the

second year.

Second year. Second-year courses provide additional training in various subfields of the social sciences.

In the fall quarter, all second-year students are required to enroll in SS 224 and at least 18 additional units of advanced social science courses. In the winter and spring quarters, all second-year students are required to enroll in at least 27 units of advanced social science courses (three typical courses). This includes SS 299 (winter term) for all second-year students. Additionally, in each term, students will enroll in 9 units of Research in Social Science (SS 300).

Appropriate courses in other options, such as mathematics and computer science, can be substituted for advanced social science classes, with the permission of the HSS division's option representative. All classes offered for grades must be completed with a grade of B or better. Students may take independent reading and study courses, but during the second year such courses do not count toward the above requirements.

Students can tailor their second-year curriculum to their specific research interests but are expected to include at least two second-year course sequences. Such course sequences include Foundations of Political Economy (SS 210abc), Advanced Economic Theory (SS 211abc), Experimental Economics (SS 212abc), Financial Economics (SS 213abc), Topics in Theoretical and Applied Econometrics (SS 223abc), Applied Empirical Methods in the Social Sciences (SS 228abc), Theoretical and Quantitative Dimensions of Historical Development (SS 229abc), and American and Comparative Politics (SS 231abc). Students may partially fulfill the second-year sequence requirement by taking a sequence of courses in mathematics, such as Ma 108abc, Ma 110abc, Ma/ACM/IDS 140ab, or Ec 181ab.

Third year. Beginning in their third year, and in all subsequent years, all students must enroll in the 3-unit graduate student pro-seminar (SS 282abc) every quarter. Every student must make a presentation in this class at least once a year. Students in the third year may also enroll in additional courses, with the approval of their adviser. Third year students are required to take SS 281 in the quarter it is offered. In each quarter, third year students should enroll in Research in Social Science (SS 300) for the units remaining to reach 36 units.

Fourth and fifth years. Students need to register for 33 units of SS 300 and 3 units of the graduate student pro-seminar (SS 282abc).

Progress in the program, and advancement to candidacy

In addition to the coursework and examinations described above, students must enroll in at least 36 units every quarter, including summer (SS 300) and complete the following requirements.

By May 1 of the second year, each second-year student must submit an outline describing a planned paper to their paper adviser, their second reader, and the option representative. The second-year paper can be co-authored. If the co-author is another graduate student, only one of the students on the joint project can use the paper to fulfill the requirement. The person using the paper for fulfilling

the requirement is expected to do most of the actual writing of the paper that is submitted. The final paper is due on September 15. If the paper adviser and the second reader both find that a student's second-year paper is satisfactory, the student advances to the third year. If they do not, the social science faculty, as a whole, will review the student's paper. If they decide that the paper is not satisfactory, they may terminate the student from the program. At the end of the second year, the social science faculty will also meet and assess each second-year student's ability for clear self-expression in both oral and written English. Also, starting their second year, students are expected to TA a minimum of three quarters during their graduate career.

Third-year students must write a research paper and present it to the faculty before the start of the fourth year. The third-year paper can be co-authored, under the same conditions that apply to the second-year paper, but not with Caltech faculty. It should be worked on in consultation with and under the direction of the student's primary adviser. The option representative will appoint a second third-year paper reader, who must be a member of the social sciences professorial faculty. The adviser and second reader will monitor progress and advise the student on the third-year paper. The paper and the presentation must demonstrate to the faculty that the student is capable of undertaking original research and presenting it to a scholarly audience.

After completion of the third-year paper presentation, the social science faculty evaluates the student's overall performance and research potential. This review is based primarily upon the third-year paper, but the faculty also verifies that the student has satisfactorily completed all previous requirements.

If this evaluation is favorable, the student is admitted to candidacy for the Ph.D. If the faculty evaluation is unfavorable, the student may be terminated from the program.

Organization of Thesis Committee

By October 1 of the third year, each student selects a primary adviser. The adviser must be a professorial member of the social science faculty at Caltech. It is possible to change advisers, in consultation with the option representative, if a student's research interests change. Students, in consultation with their adviser, must select two additional thesis committee members after the student has advanced to candidacy (normally by the beginning of their fourth year). After a student advances to candidacy, the division chairperson, in consultation with the option representative, shall select a fourth member of the committee with an eye to representing the diverse interests of the social science faculty. One of the four members of the thesis committee may be emeritus faculty, research faculty, or an external scholar, with the approval of the option representative and the dean of graduate studies. The chair of the thesis committee must be someone other than the primary adviser, who will be appointed by the social science option representative in consultation with the primary adviser. The thesis committee will also serve as the examination committee at the thesis defense.

SS Degree of Doctor of Philosophy

By November 1 of their fourth year, students must complete a dissertation prospectus that outlines the proposed dissertation work and present a tentative schedule detailing when the components of the dissertation are to be completed. The prospectus must clearly identify a project, or dissertation components, that should culminate in a job market paper at the beginning of the student's fifth year (August before the start of the fifth year, in the case of students who seek a position in political science). The prospectus must be submitted to the thesis committee by November 1. Approval or rejection of it should be communicated by the principal adviser to the option representative no later than December 1.

By May 1 of the fourth year, the student is required to convene a thesis prospectus seminar with their thesis committee. In this seminar, the student is to report on the current status of their dissertation research and outline a plan and timeline for completing it. The seminar must be based on the student's planned job market paper, and a draft of this paper must accompany the proposal. The student and the the-sis committee should reach a clear, mutual under-standing as to what additional work needs to be done to complete and to successfully defend their dissertation.

After the dissertation is completed, the student, in consultation with their adviser, must schedule an oral thesis examination to defend their dissertation. The student must provide a written copy of their dissertation to the option representative and all members of the examination committee, and complete the examination notification in Regis, not less than two weeks prior to the thesis examination date. The dissertation is expected to represent publishable, original research.

Courses

Courses numbered below 100 are taken primarily by undergraduate students. Those numbered from 100 to 199 are taken by both undergraduates and graduates, and those numbered 200 and above are taken primarily by graduate students.

The school year is divided into three terms. The number of units assigned in any term to any subject represents the number of hours spent in class, in laboratory, and estimated to be spent in preparation per week. In the following schedules, figures in parentheses denote hours in class (first figure), hours in laboratory (second figure), and hours of outside preparation (third figure).

At the end of the seventh week of each term, a list of courses to be offered the following term is published by the Registrar's Office. On the day of registration (see Academic Calendar), an updated and revised course schedule is published announcing the courses, class hours, and room assignments for the term. Students may not schedule two courses taught at the same time.

Abbreviations

Ae	Aerospace
An	Anthropology
ACM	Applied and Computational Math
AM	Applied Mechanics
APh	Applied Physics
Ay	Astrophysics
BMB	Biochemistry and Molecular Biophysics
BE	Bioengineering
Bi	Biology
BEM	Business Economics and Management
ChE	Chemical Engineering
Ch	Chemistry
CE	Civil Engineering
CNS	Computation and Neural Systems
CS	Computer Science
CMS	Computing and Mathematical Sciences
CDS	Control and Dynamical Systems
Ec	Economics
EE	Electrical Engineering
EST	Energy Science and Technology
E	Engineering
En	English
ESL	English as a Second Language
ESE	Environmental Science and Engineering
FS	First-Year Seminars
Ge	Geology
H	History
HPS	History and Philosophy of Science
Hum	Humanities
IDS	Information and Data Sciences
IST	Information Science and Technology
IC	Integrated Core
L	Languages
Law	Law
MS	Materials Science
Ma	Mathematics
ME	Mechanical Engineering
MedE	Medical Engineering
Mu	Music
NB	Neurobiology
PVA	Performing and Visual Arts
Pl	Philosophy
PE	Physical Education
Ph	Physics
PS	Political Science
Psy	Psychology
SEC	Scientific and Engineering Communication
SS	Social Science
SA	Student Activities
VC	Visual Culture
Wr	Writing

AEROSPACE

Ae 100. Research in Aerospace. *Units to be arranged in accordance with work accomplished;* Open to suitably qualified undergraduates and first-year graduate students under the direction of the staff. Credit is based on the satisfactory completion of a substantive research report, which must be approved by the Ae 100 adviser and by the option representative.

Ae/APh/CE/ME 101 abc. Fluid Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: APh 17 or ME 11 abc, and ME 12 or equivalent, ACM 95/100 or equivalent (may be taken concurrently).* Fundamentals of fluid mechanics. Microscopic and macroscopic properties of liquids and gases; the continuum hypothesis; review of thermodynamics; general equations of motion; kinematics; stresses; constitutive relations; vorticity, circulation; Bernoulli's equation; potential flow; thin-airfoil theory; surface gravity waves; buoyancy-driven flows; rotating flows; viscous creeping flow; viscous boundary layers; introduction to stability and turbulence; quasi one-dimensional compressible flow; shock waves; unsteady compressible flow; and acoustics. Instructors: Pullin, Dimotakis, Lozano-Duran.

Ae/AM/CE/ME 102 abc. Mechanics of Structures and Solids. *9 units (3-0-6); first, second, third terms. Prerequisites: ME 12 abc.* Introduction to continuum mechanics: kinematics, balance laws, constitutive laws with an emphasis on solids. Static and dynamic stress analysis. Two- and three-dimensional theory of stressed elastic solids. Wave propagation. Analysis of rods, plates and shells with applications in a variety of fields. Variational theorems and approximate solutions. Elastic stability. Instructors: Lapusta, Ravichandran, Pellegrino.

Ae 103 ab. Aerospace Control Systems. *9 units (3-0-6); first, second terms. Prerequisites: ACM 104, as well as ACM 100 a (or equivalent), can be taken concurrently.* Part a: Linear state space systems, including concepts of controllability/reachability and observability. State feedback and optimal control. Frequency domain tools (Bode plots, Nyquist analysis, input/output performance). Part b: Optimization-based design of control systems, including optimal control and receding horizon control. Introductory random processes and optimal estimation. Kalman filtering and nonlinear filtering methods for autonomous systems. Instructor: Rahmani.

Ae/APh 104 abc. Experimental Methods. *9 units (3-0-6) first term; (0-6-3) second, third terms; first, second, third terms. Prerequisites: ACM 95/100 ab or equivalent (may be taken concurrently), Ae/APh/CE/ME 101 abc or equivalent (may be taken concurrently).* Lectures on experiment design and implementation. Measurement methods, transducer fundamentals, instrumentation, optical systems, signal processing, noise theory, analog and digital electronic fundamentals, with data acquisition and processing systems. Experiments (second and third terms) in solid

and fluid mechanics with emphasis on current research methods. Instructors: Dabiri, Austin.

Ae 105 abc. Space Engineering. *9 units (3-0-6) first term, (2-4-3) second term, (0-8-1) third term; first, second, third terms. Prerequisites: ME 11 abc and ME 12 abc or equivalent.* Part a: Design of space missions based on astrodynamics. Topics include conic orbits with perturbations (J2, drag, and solar radiation pressure), Lambert's Theorem, periodic orbits and ground tracks, invariant manifolds, and the variational equation with mission applications to planetary flybys, constellation, formation flying, and low energy planetary capture and landing. Part b: Introduction to spacecraft systems and subsystems, mission design, rocket mechanics, launch vehicles, and space environments; spacecraft mechanical, structural, and thermal design; communication and power systems; preliminary discussion and setup for team project leading to system requirements review. Part c: Team project leading to preliminary design review and critical design review. Instructors: Campagnola, Watkins.

CE/Ae/AM 108. Computational Mechanics. *9 units (3-5-1);* For course description, see Civil Engineering

Ae 115 ab. Spacecraft Navigation. *9 units (3-0-6); first, second terms. Prerequisites: CDS 110 a.* This course will survey all aspects of modern spacecraft navigation, including astrodynamics, tracking systems for both low-Earth and deep-space applications (including the Global Positioning System and the Deep Space Network observables), and the statistical orbit determination problem (in both the batch and sequential Kalman filter implementations). The course will describe some of the scientific applications directly derived from precision orbital knowledge, such as planetary gravity field and topography modeling. Numerous examples drawn from actual missions as navigated at JPL will be discussed. Not offered 2025-26.

Ae/ME 118. Classical Thermodynamics. *9 units (3-0-6); first term. Prerequisites: ME 11 abc, ME 12 abc, or equivalent.* Fundamentals of Classical Thermodynamics. Basic laws of thermodynamics, work and heat, entropy and available work, and thermal systems. Equations of state, compressibility functions, and the Law of Corresponding States. Thermodynamic potentials, phase equilibrium, phase transitions, and thermodynamic properties of solids, liquids, and gases. Examples will be drawn from fluid dynamics, solid mechanics, energy systems, and thermal-science applications. Instructor: Dimotakis.

ME/Ae 120. Combustion Fundamentals. *9 units (3-0-6);* For course description, see Mechanical Engineering

Ae 121 abc. Space Propulsion. *9 units (3-0-6); first, second, third terms. Prerequisites: Open to all graduate students and to seniors with instructor's permission.* Ae 121 is designed to introduce the fundamentals of chemical, electric and advanced propulsion

technologies. The course focuses on the thermochemistry and aerodynamics of chemical and electrothermal propulsion systems, the physics of ionized gases and electrostatic and electromagnetic processes in electric thrusters. These analyses provide the opportunity to introduce the basic concepts of non-equilibrium gas dynamics and kinetic theory. Specific technologies such as launch vehicle rocket engines, monopropellant engines, arcjets, ion thrusters, magnetoplasmadynamic engines and Hall thrusters will be discussed. Ae 121 also provides an introduction to advanced propulsion concepts such as solar sails and antimatter rockets. Instructor: Polk.

Ae 150 abc. Aerospace Engineering Seminar. *1 unit; first, second, third terms.* Speakers from campus and outside research and manufacturing organizations discuss current problems and advances in aerospace engineering. Graded pass/fail. Instructor: Austin.

APh/Ph/Ae/MS 153. Fundamentals of Energy and Mass Transport in Small Scale Systems. *9 units (3-0-6);* For course description, see Applied Physics

EE/Ae 157 ab. Introduction to the Physics of Remote Sensing. *9 units (3-0-6);* For course description, see Electrical Engineering

Ae/Ge/ME 160 ab. Continuum Mechanics of Fluids and Solids. *9 units (3-0-6); first, second terms..* Elements of Cartesian tensors. Configurations and motions of a body. Kinematics-study of deformations, rotations and stretches, polar decomposition. Lagrangian and Eulerian strain velocity and spin tensor fields. Irrotational motions, rigid motions. Kinetics-balance laws. Linear and angular momentum, force, traction stress. Cauchy's theorem, properties of Cauchy's stress. Equations of motion, equilibrium equations. Power theorem, nominal (Piola-Kirchoff) stress. Thermodynamics of bodies. Internal energy, heat flux, heat supply. Laws of thermodynamics, notions of entropy, absolute temperature. Entropy inequality (Clausius-Duhem). Examples of special classes of constitutive laws for materials without memory. Objective rates, corotational, convected rates. Principles of materials frame indifference. Examples: the isotropic Navier-Stokes fluid, the isotropic thermoelastic solid. Basics of finite differences, finite elements, and boundary integral methods, and their applications to continuum mechanics problems illustrating a variety of classes of constitutive laws. Instructors: Lapusta, Bhattacharya.

Ae/CE 165 ab. Mechanics of Composite Materials and Structures. *9 units (2-2-5); first, second terms. Prerequisites: Ae/AM/CE/ME 102 abc or equivalent and/or instructor's permission.* Introduction and fabrication technology, elastic deformation of composites, stiffness bounds, on- and off-axis elastic constants for a lamina, elastic deformation of multidirectional laminates (lamination theory, ABD matrix), effective hygrothermal properties, mechanisms of yield and failure for a laminate, strength of a single ply, failure models, splitting and delamination. Experimental methods for characterization and testing of composite

materials. Design criteria, application of design methods to select a suitable laminate using composite design software, hand layup of a simple laminate and measurement of its stiffness and thermoelastic coefficients. Not offered 2025-26. . Instructor: Pellegrino.

Ae 200. Advanced Research in Aerospace. *Units to be arranged;* Ae.E. or Ph.D. thesis level research under the direction of the staff. A written research report must be submitted during finals week each term.

Ae 201 ab. Advanced Fluid Mechanics. *9 units (3-0-6); first. Prerequisites: Ae/APh/CE/ME 101abc, or equivalent; Ae/ME 118, or equivalent; ACM/IDS 101 (may be taken concurrently).* Extensions on the foundations of the mechanics of fluids. Basic concepts will be emphasized; transition from incompressible and potential flow to weakly compressible flow; acoustics and sound generation; transonic flow; fully compressible flow; flow past bodies and shock waves; small-Mach number expansion; Navier-Stokes shock structure; elements of the kinetic theory of gases; Lagrangian form of equations of motion; velocity-gradient tensor and vorticity; vortex dynamics; exact solutions; incompressible potential flow; free-streamline flows; scalar mixing. only part b offered in 2025-26. Instructor: Pullin.

Ae 204 ab. Technical Fluid Mechanics. *9 units (3-0-6); second, third terms. Prerequisites: Ae/APh/CE/ME 101 abc or equivalent.* External and internal flow problems encountered in engineering, for which only empirical methods exist. Turbulent shear flow, separation, transition, three-dimensional and nonsteady effects. Basis of engineering practice in the design of devices such as mixers, ejectors, diffusers, and control valves. Studies of flow-induced oscillations, wind effects on structures, vehicle aerodynamics. Not offered 2025-26.

Ae 205 ab. Advanced Space Project. *9 units (2-4-3); second, third terms. Prerequisites: Ae 105 abc.* This is an advanced course on the design and implementation of space projects and it is currently focused on the flight project Autonomous Assembly of a Reconfigurable Space Telescope (AAReST). The objective is to be ready for launch and operation in 2015. Each student will be responsible for a specific activity, chosen from the following: optimization of telescope system architecture; design, assembly and testing of telescope optics; telescope calibration procedure and algorithms for wavefront control; thermal analysis; boom design and deployment test methods; effects of spacecraft dynamics on telescope performance; environmental testing of telescope system. Each student will prepare a survey of the state of the art for the selected activity, and then develop a design/implementation plan, execute the plan and present the results in a final report. Not offered 2025-26.

Ae 208 abc. GALCIT Colloquium. *1 unit; first, second, third terms.* A seminar course in fluid, solid, space, and bio mechanics. Weekly lectures on current developments are presented by staff members, graduate students, and visiting scientists and engineers. Graded pass/fail.

Instructor: Gharib.

Ae/AM/MS/ME 213. Mechanics and Materials Aspects of Fracture. *9 units (3-0-6); first term. Prerequisites: Ae/AM/CE/ME 102 abc (concurrently) or equivalent and instructor's permission.* Analytical and experimental techniques in the study of fracture in metallic and nonmetallic solids. Mechanics of brittle and ductile fracture; connections between the continuum descriptions of fracture and micromechanisms. Discussion of elastic-plastic fracture analysis and fracture criteria. Special topics include fracture by cleavage, void growth, rate sensitivity, crack deflection and toughening mechanisms, as well as fracture of nontraditional materials. Fatigue crack growth and life prediction techniques will also be discussed. In addition, "dynamic" stress wave dominated, failure initiation growth and arrest phenomena will be covered. This will include traditional dynamic fracture considerations as well as discussions of failure by adiabatic shear localization. Not offered 2025-26.

Ae/AM/CE/ME 214. Computational Solid Mechanics. *9 units (3-5-1); second term. Prerequisites: ACM 100 ab or equivalent; CE/AM/Ae 108 ab or equivalent or instructor's permission; Ae/AM/CE/ME 102 abc or instructor's permission.* This course focuses on the analysis of elastic thin shell structures in the large deformation regime. Problems of interest include softening behavior, bifurcations, loss of stability and localization. Introduction to the use of numerical methods in the solution of solid mechanics and multiscale mechanics problems. Variational principles. Finite element and isogeometric formulations for thin shells. Time integration, initial boundary value problems. Error estimation. Accuracy, stability and convergence. Iterative solution methods. Adaptive strategies. Not offered 2025-26.

Ae/AM/ME 215. Dynamic Behavior of Materials. *9 units (3-0-6); third term. Prerequisites: ACM 100 abc or AM 125 abc; Ae/AM/CE/ME 102 abc.* Fundamentals of theory of wave propagation; plane waves, wave guides, dispersion relations; dynamic plasticity, adiabatic shear banding; dynamic fracture; shock waves, equation of state. Instructor: Ravichandran.

Ae/ME/APh 218. Statistical Mechanics. *9 units (3-0-6); third term. Prerequisites: Ae/ME 118, or equivalent.* Overview of probability and statistics, and the Maxwell-Boltzmann distribution. Overview and elements of Quantum Mechanics, degenerate energy states, particles in a box, and energy-state phase space. Statistics of indistinguishable elementary particles, Fermi-Dirac and Bose-Einstein statistics, partition functions, connections with classical thermodynamics, and the Law of Equipartition. Examples from equilibrium in fluids, solid-state physics, and others. Not offered 2025-26.

Ae 220. Theory of Structures. *9 units (3-0-6); first term. Prerequisites: Ae/AM/CE/ME 102 abc.* Fundamentals of buckling and stability, total potential energy and equilibrium approaches; snap-through and

bifurcation instabilities; eigenvalues and eigenvectors of stiffness matrix; Rayleigh-Ritz estimates of buckling loads; buckling of rods; imperfection sensitivity; elastic-plastic buckling; buckling of plates and shells. Selected topics: localization and wrinkling of membranes and solids; stability landscapes for shells and other topics. Not offered 2025-26. Instructor: Pellegrino.

Ae/CE 221. Space Structures. *9 units (3-0-6); first term. Prerequisites: Ae/AM/CE/ME 102 abc or equivalent (may be taken concurrently).* This course examines the links between form, geometric shape, and structural performance. It deals with different ways of breaking up a continuum, and how this affects global structural properties; structural concepts and preliminary design methods that are used in tension structures and deployable structures. Geometric foundations, polyhedra and tessellations, surfaces; space frames, examples of space frames, stiffness and structural efficiency of frames with different repeating units; sandwich plates; cable and membrane structures, form-finding, wrinkle-free pneumatic domes, balloons, tension-stabilized struts, tensegrity domes; deployable and adaptive structures, coiled rods and their applications, flexible shells, membranes, structural mechanisms, actuators, concepts for adaptive trusses and manipulators. Instructor: Pellegrino.

Ae/AM/ME 223. Plasticity. *9 units (3-0-6); second term. Prerequisites: Ae/AM/CE/ME 102 abc or instructor's permission.* Theory of dislocations in crystalline media. Characteristics of dislocations and their influence on the mechanical behavior in various crystal structures. Application of dislocation theory to single and polycrystal plasticity. Theory of the inelastic behavior of materials with negligible time effects. Experimental background for metals and fundamental postulates for plastic stress-strain relations. Variational principles for incremental elastic-plastic problems, uniqueness. Upper and lower bound theorems of limit analysis and shakedown. Slip line theory and applications. Additional topics may include soils, creep and rate-sensitive effects in metals, the thermodynamics of plastic deformation, and experimental methods in plasticity. Not offered 2025-26. Instructor: Pellegrino.

ME/MS/Ae/AM 224. Multifunctional Materials. *9 units (3-0-6);* For course description, see Mechanical Engineering

Ae/AM/ME/Ge 225. Special Topics in Solid Mechanics. *Units to be arranged; first, second, third terms.* Subject matter changes depending on staff and student interest. Not offered 2025-26.

Ae/ACM/ME 232 ab. Computational Fluid Dynamics. *9 units (3-0-6); second, third terms. Prerequisites: Ae/APh/CE/ME 101 abc or equivalent; ACM 100 ab or equivalent; ACM 104.* Development and analysis of algorithms used in the solution of fluid mechanics problems. Numerical analysis of discretization schemes for partial differential equations including interpolation, integration, spatial discretization, systems of ordinary differential equations; stability, accuracy, aliasing, Gibbs and

Runge phenomena, numerical dissipation and dispersion; boundary conditions. Survey of finite difference, finite element, finite volume and spectral approximations for the numerical solution of the incompressible and compressible Euler and Navier-Stokes equations, including shock-capturing methods. Instructors: Colonius, Meiron.

Ae 233. Hydrodynamic Stability. *9 units (3-0-6); second term. Prerequisites: ACM 95/100 ab, ACM 104 or equivalent and Ae/APh/CE/ME 101 abc.* Laminar-stability theory as a guide to laminar-turbulent transition. Rayleigh equation, instability criteria, and response to small inviscid disturbances. Discussion of Kelvin-Helmholtz, Rayleigh-Taylor, Richtmyer-Meshkov, and other instabilities, for example, in geophysical flows. The Orr-Sommerfeld equation, the dual role of viscosity, and boundary-layer stability. Non-normality of the linearized Navier-Stokes operator, and transient growth. Weakly nonlinear stability theory and phenomenological theories of turbulence. Instructor: Meiron.

Ae 234 ab. Hypersonic Aerodynamics. *9 units (3-0-6); third term. Prerequisites: Ae/APh/CE/ME 101 abc or equivalent, AM 125 abc, or instructor's permission.* An advanced course dealing with aerodynamic problems of flight at hyper-sonic speeds. Topics are selected from hypersonic small-disturbance theory, blunt-body theory, boundary layers and shock waves in real gases, heat and mass transfer, testing facilities and experiment. Not offered 2025-26. Instructor: Austin.

Ae 235. Rarefied Gasdynamics. *9 units (3-0-6); first term.* Molecular description of matter; distribution functions; discrete-velocity gases. Kinetic theory: free-path theory, internal degrees of freedom. Boltzmann equation: BBGKY hierarchy and closure, H theorem, Euler equations, Chapman-Enskog procedure, free-molecule flows. Collisionless and transitional flows. Direct simulation Monte Carlo methods. Applications. Not offered 2025-26.

Ae 237 ab. Nonsteady Gasdynamics. *9 units (3-0-6); second, third terms. Prerequisites: Ae/APh/CE/ME 101 abc, ACM100ab or ACM101ab, or instructor's permission.* Part a: dynamics of shock waves, expansion waves, and related discontinuities in gases. Adiabatic phase-transformation waves. Interaction of waves in one- and two-dimensional flows. Boundary layers and shock structure. Applications and shock tube techniques. Part b: shock and detonation waves in solids and liquids. Equations of state for hydrodynamic computations in solids, liquids, and explosive reaction products. CJ and ZND models of detonation in solids and liquids. Propagation of shock waves and initiation of reaction in explosives. Interactions of detonation waves with water and metals. Not offered 2025-26. .

Ae 239 ab. Turbulence. *9 units (3-0-6); second, third terms. Prerequisites: Ae/APh/CE/ME 101abc, or equivalent; ACM 95/100ab. Recommended: ACM/IDS 101 (may be taken concurrently); Ae233.* Reynolds number, transition from steady to unsteady, chaotic, and

turbulent flow. Reynolds-averaged equations. Statistical description of turbulence. Physical and spectral models. Homogeneous isotropic turbulence, intermediate and small scales. Large-scale structure, and turbulent free and wall-bounded shear flows. Turbulent mixing. Instructors: Lozano-Duran, Bae.

Ae 240. Special Topics in Fluid Mechanics. *Units to be arranged; first, second, third terms.* Topics and subject matter descriptions change each year depending upon staff and student interest.

Ae 241. Special Topics in Experimental Fluid and Solid Mechanics. *Units to be arranged; first, second, third terms. Prerequisites: Ae/APh 104 or equivalent or instructor's permission.* Subject matter changes depending upon staff and student interest. Not offered 2025-26.

Ae/BE 242. Biological Flows: Propulsion. *9 units (3-0-6); third term. Prerequisites: Ae/APh/CE/ME 101 abc or equivalent or ChE 103 a.* Physical principles of unsteady fluid momentum transport: equations of motion, dimensional analysis, conservation laws. Unsteady vortex dynamics: vorticity generation and dynamics, vortex dipoles/rings, wake structure in unsteady flows. Life in moving fluids: unsteady drag, added-mass effects, virtual buoyancy, bounding and schooling, wake capture. Thrust generation by flapping, undulating, rowing, jetting. Low Reynolds number propulsion. Bioinspired design of propulsion devices. Not offered 2025-26.

MedE/BE/Ae 243. Physiological Mechanics. *9 units (3-0-6);* For course description, see Medical Engineering

Ae 250. Reading and Independent Study. *Units to be arranged; first, second, third terms.* Graded pass/fail only.

Ae/CDS/ME 251 ab. Closed Loop Flow Control. *9 units (3-0-6 a, 1-6-1 b); second, third term. Prerequisites: ACM 100 abc, Ae/APh/CE/ME 101 abc or equivalent.* This course seeks to introduce students to recent developments in theoretical and practical aspects of applying control to flow phenomena and fluid systems. Lecture topics in the second term drawn from: the objectives of flow control; a review of relevant concepts from classical and modern control theory; high-fidelity and reduced-order modeling; principles and design of actuators and sensors. Third term: laboratory work in open- and closed-loop control of boundary layers, turbulence, aerodynamic forces, bluff body drag, combustion oscillations and flow-acoustic oscillations. Not offered 2025-26.

Ae/AM/CE/ME/Ge 265 ab. Static and Dynamic Failure of Brittle Solids and Interfaces, from the Micro to the Mega. *9 units (3-0-6); second term. Prerequisites: Ae/AM/CE/ME 102 abc or equivalent and/or instructor's permission.* Linear elastic fracture mechanics of homogeneous brittle solids (e.g. geo-materials, ceramics, metallic glasses); small scale yielding concepts; experimental methods in

fracture, fracture of bi-material interfaces with applications to composites as well as bonded and layered engineering and geological structures; thin-film and micro-electronic components and systems; dynamic fracture mechanics of homogeneous engineering materials; dynamic shear dominated failure of coherent and incoherent interfaces at all length scales; dynamic rupture of frictional interfaces with application to earthquake source mechanics; allowable rupture speeds regimes and connections to earthquake seismology and the generation of Tsunamis. Part B will not be offered in 2025-26. . Instructor: Rosakis.

ME/Ge/Ae 266 ab. Fracture and Frictional Faulting. *9 units (3-0-6);* For course description, see Mechanical Engineering

ANTHROPOLOGY

An 97. Undergraduate Research. *Units to be arranged; any term. Prerequisites: advanced Anthropology and instructor's permission.* This course offers advanced undergraduates the opportunity to pursue research in Anthropology individually or in a small group. Graded pass/fail. Not offered 2025-26.

An 101. Selected Topics in Anthropology. *Units to be determined by arrangement with the instructor; offered by announcement.* Topics to be determined by instructor. Not offered 2025-26.

An/PS 127. Corruption. *9 units (3-0-6); first, second terms. Prerequisites: AN 14 or PS 12.* Corruption taxes economies and individuals in both the developing and the developed world. We will examine what corruption means in different places and contexts, from grand financial scandals to misappropriation of all manner of public resources. How do we measure corruption? What are its costs and social consequences? What have culture and psychology got to do with it? How much do governance and a free press matter? What are the potential solutions? Students will work closely with the professor to develop an independent and original research project of their choice. Limited enrollment. Not offered 2025-26.

APPLIED & COMPUTATIONAL MATH

ACM 11. Introduction to Computational Science and Engineering. *6 units (2-2-2); third term. Prerequisites: Ma 1 ab, Co-requisite Ma 1 c. CS 1 or prior programming experience recommended.* This course is intended to serve as a practical introduction to the methods of computational science and engineering for students in all majors. The goal is to provide students exposure to and hands-on experience with commonly-used computational methods in science and engineering, with theoretical considerations confined to a level appropriate for first-year undergraduate students. Topics covered include computational

simulation by discretization in space and time, numerical solution of linear and nonlinear equations, optimization, uncertainty quantification, and function approximation via interpolation and regression. Emphasis is on understanding trade-offs between computational effort and accuracy, and on developing working knowledge of how these tools can be used to solve a wide range of problems arising in applied math, science, and engineering. Assignments and in-class activities use MATLAB. No prior experience with MATLAB expected. Instructors: Park, Babecki.

ACM 80 abc. Undergraduate Thesis. *9 units; first, second, third terms. Prerequisites: instructor's permission, which should be obtained sufficiently early to allow time for planning the research.* Individual research project, carried out under the supervision of a member of the ACM faculty (or other faculty as approved by the ACM undergraduate option representative). Projects must include significant design effort. Written report required. Open only to upper class students. Not offered on a pass/fail basis. Instructor: Staff.

ACM 81 abc. Undergraduate Projects in Applied and Computational Mathematics. *Units are assigned in accordance with work accomplished; first, second, third terms. Prerequisites: Consent of supervisor is required before registering.* Supervised research or development in ACM by undergraduates. The topic must be approved by the project supervisor, and a formal final report must be presented on completion of research. Graded pass/fail. Instructor: Staff.

ACM 95/100 ab. Introductory Methods of Applied Mathematics for the Physical Sciences. *12 units (4-0-8); second, third terms. Prerequisites: Ma 1 abc, Ma 2 or equivalents.* Complex analysis: analyticity, Laurent series, contour integration, residue calculus. Ordinary differential equations: linear initial value problems, linear boundary value problems, Sturm-Liouville theory, eigenfunction expansions, transform methods, Green's functions. Linear partial differential equations: heat equation, separation of variables, Laplace equation, transform methods, wave equation, method of characteristics, Green's functions. Instructors: Zuev (second term) and Hoffmann, Cao (third term).

ACM/IDS 101 ab. Methods of Applied Mathematics. *12 units (4-4-4); first, second terms. Prerequisites: Math 2/102 and ACM 95 ab or equivalent.* First term: Brief review of the elements of complex analysis and complex-variable methods. Asymptotic expansions, asymptotic evaluation of integrals (Laplace method, stationary phase, steepest descents), perturbation methods, WKB theory, boundary-layer theory, matched asymptotic expansions with first-order and high-order matching. Method of multiple scales for oscillatory systems. Second term: Applied spectral theory, special functions, generalized eigenfunction expansions, convergence theory. Gibbs and Runge phenomena and their resolution. Chebyshev expansion and Fourier Continuation methods. Review of numerical stability theory for time evolution. Fast spectrally-accurate PDE solvers for linear and nonlinear Partial Differential Equations in general domains. Integral-equations

methods for linear partial differential equation in general domains (Laplace, Helmholtz, Schroedinger, Maxwell, Stokes). Homework problems in both 101 a and 101 b include theoretical questions as well as programming implementations of the mathematical and numerical methods studied in class. Instructor: Bruno.

ACM/IDS 104. Applied Linear Algebra. *9 units (3-1-5); first term. Prerequisites: Ma 1 abc, some familiarity with MATLAB, e.g. ACM 11 is desired.* This is an intermediate linear algebra course aimed at a diverse group of students, including junior and senior majors in applied mathematics, sciences and engineering. The focus is on applications. Matrix factorizations play a central role. Topics covered include linear systems, vector spaces and bases, inner products, norms, minimization, the Cholesky factorization, least squares approximation, data fitting, interpolation, orthogonality, the QR factorization, ill-conditioned systems, discrete Fourier series and the fast Fourier transform, eigenvalues and eigenvectors, the spectral theorem, optimization principles for eigenvalues, singular value decomposition, condition number, principal component analysis, the Schur decomposition, methods for computing eigenvalues, non-negative matrices, graphs, networks, random walks, the Perron-Frobenius theorem, PageRank algorithm. Instructor: Zuev.

ACM/EE 106 ab. Introductory Methods of Computational Mathematics. *12 units (3-0-9); first, second terms. Prerequisites: For ACM/EE 106 a, Ma 1 abc, Ma 2, Ma 3, ACM 11; for ACM/EE 106 b, ACM 95/100 ab or equivalent.* The sequence covers the introductory methods in both theory and implementation of numerical linear algebra, approximation theory, ordinary differential equations, and partial differential equations. The linear algebra parts cover basic methods such as direct and iterative solution of large linear systems, including LU decomposition, splitting method (Jacobi iteration, Gauss-Seidel iteration); eigenvalue and vector computations including the power method, QR iteration and Lanczos iteration; nonlinear algebraic solvers. The approximation theory includes data fitting; interpolation using Fourier transform, orthogonal polynomials and splines; least square method, and numerical quadrature. The ODE parts include initial and boundary value problems. The PDE parts include finite difference and finite element for elliptic/parabolic/hyperbolic equations. Study of numerical PDE will include stability analysis. Programming is a significant part of the course. Instructor: Hou.

CMS/ACM/IDS 107 ab. Linear Analysis with Applications. *12 units (3-0-9);* For course description, see Computing and Mathematical Sciences

ACM 109. Mathematical Modelling. *9 units (3-0-6); third term.* Prerequisites ACM 95/100 ab or equivalent. This course gives an overview of different mathematical models used to describe a variety of phenomena arising in the biological, engineering, physical and social sciences. Emphasis will be placed on the principles used to develop these models, and on the unity and cross-cutting nature of the

mathematical and computational tools used to study them. Applications will include quantum, atomistic and continuum modeling of materials; epidemics, reacting-diffusing systems; crowd modeling and opinion formation. Mathematical tools will include ordinary, partial and stochastic differential equations, as well as Markov chains and other stochastic processes. Not offered 2025-26.

Ec/ACM/CS 112. Bayesian Statistics. *9 units (3-0-6);* For course description, see Economics

ACM/EE/IDS 116. Introduction to Probability Models. *9 units (3-1-5); first term. Prerequisites: Ma 3 or EE 55, some familiarity with MATLAB, e.g. ACM 11, is desired.* This course introduces students to the fundamental concepts, methods, and models of applied probability and stochastic processes. The course is application oriented and focuses on the development of probabilistic thinking and intuitive feel of the subject rather than on a more traditional formal approach based on measure theory. The main goal is to equip science and engineering students with necessary probabilistic tools they can use in future studies and research. Topics covered include sample spaces, events, probabilities of events, discrete and continuous random variables, expectation, variance, correlation, joint and marginal distributions, independence, moment generating functions, law of large numbers, central limit theorem, random vectors and matrices, random graphs, Gaussian vectors, branching, Poisson, and counting processes, general discrete- and continuous-timed processes, auto- and cross-correlation functions, stationary processes, power spectral densities. Instructor: Zuev.

CMS/ACM 117. Probability Theory and Computational Mathematics. *12 units (3-0-9);* For course description, see Computing and Mathematical Sciences

ACM 118. Gaussian Processes and kernel methods. *12 units (3-0-9); second term. Prerequisites: CMS/ACM/IDS 107 or equivalent, ACM 116 or equivalent, or permission of the instructor.* This course provides a thorough and comprehensive exploration of Gaussian processes and kernel methods, bridging foundational theory with practical applications in regression, learning, and numerical analysis. It covers Gaussian vectors, processes, fields, and measures, with a particular focus on regression techniques. The course delves into kernel methods and Reproducing Kernel Hilbert Spaces (RKHS), examining key concepts such as Kernel PCA, LDA, CCA, kernel mean embedding, and operator-valued kernels. A central theme will be the interplay between kernel methods and optimal recovery techniques, with applications in statistical numerical approximation, signal processing, and machine learning. Instructor: Owhadi.

CMS/ACM/EE 122. Mathematical Optimization. *12 units (4-0-8);* For course description, see Computing and Mathematical Sciences

AM/ACM 127. Calculus of Variations. *9 units (3-0-6);* For course description, see Applied Mechanics

Ma/ACM/IDS 140 abc. Probability. *9 units (3-0-6);* For course description, see Mathematics

Ma/ACM 142 ab. Ordinary and Partial Differential Equations. *9 units (3-0-6);* For course description, see Mathematics

ACM/IDS 154. Inverse Problems and Data Assimilation. *9 units (3-0-6); Second term. Prerequisites: Basic differential equations, linear algebra, probability and statistics: ACM/IDS 104, ACM/EE 106 ab, ACM/EE/IDS 116, IDS/ACM/CS 157 or equivalent.* Models in applied mathematics often have input parameters that are uncertain; observed data can be used to learn about these parameters and thereby to improve predictive capability. The purpose of the course is to describe the mathematical and algorithmic principles of this area. The topic lies at the intersection of fields including inverse problems, differential equations, machine learning and uncertainty quantification. Applications will be drawn from the physical, biological and data sciences. Instructor: Stuart.

IDS/ACM/CS 157. Statistical Inference. *9 units (3-2-4);* For course description, see Information and Data Sciences

IDS/ACM/CS 158. Fundamentals of Statistical Learning. *9 units (3-3-3);* For course description, see Information and Data Sciences

ACM/EE/IDS 170. Mathematics of Signal Processing. *12 units (3-0-9); third term. Prerequisites: ACM/IDS 104, CMS/ACM/EE 122, and ACM/EE/IDS 116; or instructor's permission.* This course covers classical and modern approaches to problems in signal processing. Problems may include denoising, deconvolution, spectral estimation, direction-of-arrival estimation, array processing, independent component analysis, system identification, filter design, and transform coding. Methods rely heavily on linear algebra, convex optimization, and stochastic modeling. In particular, the class will cover techniques based on least-squares and on sparse modeling. Throughout the course, a computational viewpoint will be emphasized. Instructor: Hassibi.

CS/ACM 177 ab. Discrete Differential Geometry: Theory and Applications. *9 units (3-3-3);* For course description, see Computer Science

ACM/IDS 180 ab. Multiscale Modeling. *12 units (3-0-9); first, third terms. Prerequisites: CMS 107, CMS 117 or explicit email permission from instructor.* Part a: Multiscale methodology for partial differential equations (PDEs) and for stochastic differential equations (SDEs). Basic theory of underlying PDEs; basic theory of Gaussian processes; basic theory of SDEs; multiscale expansions. Part b: Transition from quantum to continuum modeling of materials. Schrodinger equation and semi-classical limit; molecular dynamics and kinetic theory; kinetic

theory, Boltzmann equation and continuum mechanics. Not offered 2025-26. Instructor: Staff.

ACM 190. Reading and Independent Study. *Units by arrangement;* Graded pass/fail only. Instructor: Staff.

ACM 201. Partial Differential Equations. *12 units (4-0-8); first term. Prerequisites: ACM 95/100 ab, ACM/IDS 101 ab, ACM 11 or equivalent.* This course offers an introduction to the theory of Partial Differential Equations (PDEs) commonly encountered across mathematics, engineering and science. The goal of the course is to study properties of different classes of linear and nonlinear PDEs (elliptic, parabolic and hyperbolic) and the behavior of their solutions using tools from functional analysis with an emphasis on applications. We will discuss representative models from different areas such as: heat equation, wave equation, advection-reaction-diffusion equation, conservation laws, shocks, predator prey models, Burger's equation, kinetic equations, gradient flows, transport equations, integral equations, Helmholtz and Schrödinger equations and Stoke's flow. In this course you will use analytical tools such as Gauss's theorem, Green's functions, weak solutions, existence and uniqueness theory, Sobolev spaces, well-posedness theory, asymptotic analysis, Fredholm theory, Fourier transforms and spectral theory. More advanced topics include: Perron's method, applications to irrotational flow, elasticity, electrostatics, special solutions, vibrations, Huygens' principle, Eikonal equations, spherical means, retarded potentials, water waves, various approximations, dispersion relations, Maxwell equations, gas dynamics, Riemann problems, single- and double-layer potentials, Navier-Stokes equations, Reynolds number, potential flow, boundary layer theory, subsonic, supersonic and transonic flow. Not offered 2025-26. Instructor: Staff.

ACM/IDS 204. Topics in Linear Algebra and Convexity. *9 units (3-0-6); third term. Prerequisites: CMS 107a and CMS/ACM 122; or instructor's permission.* The content of this course varies from year to year among advanced subjects in linear algebra, convex analysis, and related fields. Specific topics for the class include matrix analysis, operator theory, convex geometry, or convex algebraic geometry. Lectures and homework will require the ability to understand and produce mathematical proofs. Not offered 2025-26. Instructor: Staff.

ACM 206. Topics in Computational Mathematics. *9 units (3-0-6); third term. Prerequisites: ACM 106 ab; linear algebra at the level of ACM 104 or ACM 107; probability theory at the level of ACM 116 or ACM 117; some programming experience.* This course provides an introduction to Monte Carlo methods with applications in Bayesian computing and rare event sampling. Topics include Markov chain Monte Carlo (MCMC), Gibbs samplers, Langevin samplers, MCMC for infinite-dimensional problems, convergence of MCMC, parallel tempering, umbrella sampling, forward flux sampling, and sequential Monte Carlo. Emphasis is placed both on rigorous mathematical development and on practical coding experience. Not offered 2025-26. Instructor: Staff.

ACM 210. Numerical Methods for PDEs. *9 units (3-0-6); third terms. Prerequisites: ACM 11, 106 or instructor's permission.* Finite difference and finite volume methods for hyperbolic problems. Stability and error analysis of nonoscillatory numerical schemes: i) linear convection: Lax equivalence theorem, consistency, stability, convergence, truncation error, CFL condition, Fourier stability analysis, von Neumann condition, maximum principle, amplitude and phase errors, group velocity, modified equation analysis, Fourier and eigenvalue stability of systems, spectra and pseudospectra of nonnormal matrices, Kreiss matrix theorem, boundary condition analysis, group velocity and GKS normal mode analysis; ii) conservation laws: weak solutions, entropy conditions, Riemann problems, shocks, contacts, rarefactions, discrete conservation, Lax-Wendroff theorem, Godunov's method, Roe's linearization, TVD schemes, high-resolution schemes, flux and slope limiters, systems and multiple dimensions, characteristic boundary conditions; iii) adjoint equations: sensitivity analysis, boundary conditions, optimal shape design, error analysis. Interface problems, level set methods for multiphase flows, boundary integral methods, fast summation algorithms, stability issues. Spectral methods: Fourier spectral methods on infinite and periodic domains. Chebyshev spectral methods on finite domains. Spectral element methods and h-p refinement. Multiscale finite element methods for elliptic problems with multiscale coefficients. Not offered 2025-26. Instructor: Staff.

ACM/IDS 213. Topics in Optimization. *9 units (3-0-6); third term. Prerequisites: ACM/IDS 104, CMS/ACM/EE 122.* Material varies year-to-year. Example topics include discrete optimization, convex and computational algebraic geometry, numerical methods for large-scale optimization, and convex geometry. Not offered 2025-26. Instructor: Staff.

ACM/IDS 216. Markov Chains, Discrete Stochastic Processes and Applications. *9 units (3-0-6); second term. Prerequisites: ACM/EE/IDS 116 or equivalent.* Introduction to Markov chains and processes covering discrete and continuous state-spaces in both discrete and continuous time settings. Topics include irreducibility, aperiodicity, stationary and equilibrium distributions, convergence behavior, transience and recurrence, and the Ergodic Theorem. Emphasis on Markov Chain Monte Carlo (MCMC) algorithms, particularly Metropolis-Hastings and Simulated Annealing, with practical applications in scientific computing. Additional topics include coupling from the past, convergence rates, and an introduction to Markov Decision Processes. Instructor: Owhadi.

ACM 217. Advanced Topics in Probability. *9 units (3-0-6); second term. Prerequisites: CMS 107a and CMS/ACM 117; or instructor's permission.* Topic varies by year. 2023-24: Random matrix theory. This class introduces some fundamental random matrix models with applications in computational mathematics, statistics, signal processing, algorithms, and other areas. The focus is on finite-dimensional examples and comparisons with ideal models. Specific topics may include the

independent sum model, matrix concentration inequalities, geometric random matrix theory, classical ensembles and their limiting spectral properties, universality laws, and free probability. Lectures and homework will require the ability to understand and produce mathematical proofs. Not offered 2025-26. Instructor: Staff.

Ae/ACM/ME 232 ab. Computational Fluid Dynamics. *9 units (3-0-6);* For course description, see Aerospace

ACM 256. Special Topics in Applied Mathematics. *9 units (3-0-6); second term. Prerequisites: Familiarity with analysis and probability, e.g. ACM 105 and ACM 116 is desired.* Measure transport is a rich mathematical topic at the intersection of analysis, probability and optimization. The core idea behind this theory is to rearrange the mass of a reference measure to match a target measure. In particular, optimal transport seeks a rearrangement that transports mass with minimal cost. The theory of optimal transport dates back to Monge in 1781, with significant advancements by Kantorovich in 1942 and later in the '90s, e.g. by Brenier. In recent years, measure transport has become an indispensable tool for representing probability distributions and for defining measures of similarity between distributions. These methods enjoy applications in image retrieval, signal and image representation, inverse problems, cancer detection, texture and color modelling, shape and image registration, and machine learning, to name a few. This class will introduce the foundations of measure transport, present its connections and applications in various fields, and lastly explore modern computational methods for finding discrete and continuous transport maps, e.g. Sinkhorn's algorithm and normalizing flows. Not offered 2025-26. Instructor: Hoffmann.

ACM 257. Special Topics in Financial Mathematics. *9 units (3-0-6); third term. Prerequisites: ACM 95/100 or instructor's permission.* A basic knowledge of probability and statistics as well as transform methods for solving PDEs is assumed. This course develops some of the techniques of stochastic calculus and applies them to the theory of financial asset modeling. The mathematical concepts/tools developed will include introductions to random walks, Brownian motion, quadratic variation, and Ito-calculus. Connections to PDEs will be made by Feynman-Kac theorems. Concepts of risk-neutral pricing and martingale representation are introduced in the pricing of options. Topics covered will be selected from standard options, exotic options, American derivative securities, term-structure models, and jump processes. Not offered 2025-26. Instructor: Staff.

ACM 270. Advanced Topics in Applied and Computational Mathematics. *Hours and units by arrangement; first, second, third terms.* Advanced topics in applied and computational mathematics that will vary according to student and instructor interest. May be repeated for credit. Instructor: Staff.

ACM 300. Research in Applied and Computational Mathematics. *Units by arrangement;* Instructor: Staff.

APPLIED MECHANICS

Ae/AM/CE/ME 102 abc. Mechanics of Structures and Solids. *9 units (3-0-6);* For course description, see Aerospace

CE/Ae/AM 108. Computational Mechanics. *9 units (3-5-1);* For course description, see Civil Engineering

AM/ACM 127. Calculus of Variations. *9 units (3-0-6); third term. Prerequisites: ACM 95/100.* First and second variations; Euler-Lagrange equation; Hamiltonian formalism; action principle; Hamilton-Jacobi theory; stability; local and global minima; direct methods and relaxation; isoperimetric inequality; asymptotic methods and gamma convergence; selected applications to mechanics, materials science, control theory and numerical methods. Instructor: Bhattacharya.

AM/CE/ME 150 abc. Graduate Engineering Seminar. *1 unit; each term.* Students attend a graduate seminar each week of each term and submit a report about the attended seminars. At least four of the attended seminars each term should be from the Mechanical and Civil Engineering seminar series. Students not registered for the M.S. and Ph.D. degrees must receive the instructor's permission. Graded pass/fail. Instructor: Staff.

AM/CE 151. Dynamics and Vibration. *9 units (3-0-6); second term.* Equilibrium concepts, conservative and dissipative systems, Lagrange's equations, differential equations of motion for discrete single and multi degree-of-freedom systems, natural frequencies and mode shapes of these systems (Eigenvalue problem associated with the governing equations), phase plane analysis of vibrating systems, forms of damping and energy dissipated in damped systems, response to simple force pulses, harmonic and earthquake excitation, response spectrum concepts, vibration isolation, seismic instruments, dynamics of continuous systems, Hamilton's principle, axial vibration of rods and membranes, transverse vibration of strings, beams (Bernoulli-Euler and Timoshenko beam theory), and plates, traveling and standing wave solutions to motion of continuous systems, Rayleigh quotient and the Rayleigh-Ritz method to approximate natural frequencies and mode shapes of discrete and continuous systems, frequency domain solutions to dynamical systems, stability criteria for dynamical systems, and introduction to nonlinear systems and random vibration theory. Not offered 2025-26.

AM/ME 165. Finite Elasticity. *9 units (3-0-6); third term. Prerequisites: Ae/Ge/ME 160 a.* Finite theory of elasticity: constitutive theory, semi-inverse methods. Variational methods. Applications to problems of

current interest. Not offered 2025-26.

AM 200. Advanced Work in Applied Mechanics. *Hours and units by arrangement;* A faculty mentor will oversee a student proposed, independent research or study project to meet the needs of graduate students. Graded pass/fail. The consent of a faculty mentor and a written report is required for each term of work.

AM 201. Advanced Topics in Applied Mechanics. *9 units (3-0-6); third term.* The faculty will prepare courses on advanced topics to meet the needs of graduate students. Instructor: Andrade.

Ae/AM/MS/ME 213. Mechanics and Materials Aspects of Fracture. *9 units (3-0-6);* For course description, see Aerospace

Ae/AM/CE/ME 214. Computational Solid Mechanics. *9 units (3-5-1);* For course description, see Aerospace

Ae/AM/ME 215. Dynamic Behavior of Materials. *9 units (3-0-6);* For course description, see Aerospace

ME/MS/AM 221. Effective properties of heterogenous and meta-materials. *9 units (3-0-6);* For course description, see Mechanical Engineering

Ae/AM/ME 223. Plasticity. *9 units (3-0-6);* For course description, see Aerospace

ME/MS/Ae/AM 224. Multifunctional Materials. *9 units (3-0-6);* For course description, see Mechanical Engineering

Ae/AM/ME/Ge 225. Special Topics in Solid Mechanics. *Units to be arranged;* For course description, see Aerospace

AM/CE/ME 252. Linear and Nonlinear Waves in Structured Media. *9 units (2-1-6); third term.* The course will cover the basic principles of wave propagation in solid media. It will discuss the fundamental principles used to describe linear and nonlinear wave propagation in continuum and discrete media. Selected recent scientific advancements in the dynamics of periodic media will also be discussed. Students learn the basic principles governing the propagation of waves in discrete and continuum solid media. These methods can be used to engineer materials with predefined properties and to design dynamical systems for a variety of engineering applications (e.g., vibration mitigation, impact absorption and sound insulation). The course will include an experimental component, to test wave phenomena in structured media. Not offered 2025-26.

Ae/AM/CE/ME/Ge 265 ab. Static and Dynamic Failure of Brittle Solids and Interfaces, from the Micro to the Mega. *9 units (3-0-6);* For course description, see Aerospace

AM 300. Research in Applied Mechanics. *Hours and units by arrangement;* Research in the field of applied mechanics. By arrangement with members of the staff, properly qualified graduate students are directed in research.

APPLIED PHYSICS

APh/EE 9. Solid-State Electronics for Integrated Circuits. *6 units (2-2-2); first term.* Introduction to solid state electronic devices and fabrication. Topics: semiconductor physics, crystal growth and materials deposition, ion implantation and etching technology, diodes and transistors, microfluidics, nanotechnology and its applications, limitations of miniaturization. Laboratory includes semiconductor physics experiments, circuit design, lasers and optoelectronics, microfluidics and electron microscopy and characterization. Instructor: Scherer.

APh 17 abc. Thermodynamics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 1 abc, Ph 1 abc.* Introduction to the use of thermodynamics and statistical mechanics in physics and engineering. Entropy, temperature, and the principal laws of thermodynamics. Canonical equations of state. Applications to cycles, engines, phase and chemical equilibria. Probability and stochastic processes. Kinetic theory of perfect gases. Statistical mechanics. Applications to gases, gas degeneration, equilibrium radiation, and simple solids. Not offered 2025-26. Instructor: Staff.

APh/EE 23. Demonstration Lectures in Classical and Quantum Photonics. *9 units (3-0-6); second term. Prerequisites: Ph 1 abc is required; a class on waves (Ph2a or Ph12a) is strongly encouraged but not required; prior knowledge of quantum mechanics is not required..* This course focuses on basic concepts needed for understanding classical and quantum optical phenomena and their applications to modern optical components and systems. Classical optical phenomena including interference, dispersion, birefringence, diffraction, laser oscillation, and the applications of these phenomena in optical systems employing multiple-beam interferometry, Fourier-transform image processing, holography, electro-optic modulation, optical detection and heterodyning will be covered. Quantum optical phenomena like single photon emission will be discussed. Examples and demonstrations will be selected from optical communications, lidar, adaptive optical systems, nano-photonic devices and quantum communications. Visits to research laboratories in optics are expected at the end of the course. This class is optimal for sophomores/juniors/seniors who want to get their first serious exposure to optics but also might work for well-prepared and motivated First-Year students. Not offered 2025-26. Instructor: Staff.

APh/EE 24. Introductory Optics and Photonics Laboratory. *9 units (1-3-5); third term. Prerequisites: Ph 1 abc is required; APh 23 and a*

class on waves (Ph2a or Ph12a) are strongly encouraged but not required. Laboratory experiments to acquaint students with the basic aspects of Optics and Photonics Research and Technology. This course offers hands-on experience and teaches students how to handle major optical and electronic equipment and conduct experiments. It is useful for those who are thinking about a career utilizing both optical and electronic tools. Experiments encompass some of the topics and concepts covered in APh 23. Instructor: Vahala.

EE/APh 40. Physics of Electrical Engineering. *9 units (3-0-6);* For course description, see Electrical Engineering

APh 77 bc. Laboratory in Applied Physics. *9 units (0-9-0); second, third terms.* Selected experiments chosen to familiarize students with laboratory equipment, procedures, and characteristic phenomena in plasmas, fluid turbulence, fiber optics, X-ray diffraction, microwaves, high-temperature superconductivity, black-body radiation, holography, and computer interfacing of experiments. Not offered 2025-26.

APh 78 abc. Senior Thesis, Experimental. *9 units (0-9-0); first, second, third terms. Prerequisites: instructor's permission.* Supervised experimental research, open only to senior-class applied physics majors. Requirements will be set by individual faculty member, but must include a written report. The selection of topic must be approved by the Applied Physics Option Representative. Not offered on a pass/fail basis. Final grade based on written thesis and oral exam. Instructor: Staff.

APh 79 abc. Senior Thesis, Theoretical. *9 units (0-9-0); first, second, third terms. Prerequisites: instructor's permission.* Supervised theoretical research, open only to senior-class applied physics majors. Requirements will be set by individual faculty member, but must include a written report. The selection of topic must be approved by the Applied Physics Option Representative. Not offered on a pass/fail basis. Final grade based on written thesis and oral exam. This course cannot be used to satisfy the laboratory requirement in APh. Instructor: Staff.

APh 100. Advanced Work in Applied Physics. *Units in accordance with work accomplished;* Special problems relating to applied physics, arranged to meet the needs of students wishing to do advanced work. Primarily for undergraduates. Students should consult with their advisers before registering. Graded pass/fail.

Ae/APh/CE/ME 101 abc. Fluid Mechanics. *9 units (3-0-6);* For course description, see Aerospace

Ae/APh 104 abc. Experimental Methods. *9 units (3-0-6) first term; (0-6-3) second, third terms;* For course description, see Aerospace

APh/MS/ME 105 abc. States of Matter. *9 units (3-0-6); first, second, third terms. Prerequisites: APh 17 abc or equivalent.* Thermodynamics and statistical mechanics, with emphasis on gases, liquids, materials,

and condensed matter. Effects of heat, pressure, and fields on states of matter are presented with both classical thermodynamics and with statistical mechanics. Conditions of equilibrium in systems with multiple degrees of freedom. Applications include ordered states of matter and phase transitions. The three terms cover, approximately, thermodynamics, statistical mechanics, and phase transitions. Instructors: Minnich, Troian, Falson/Voorhees.

APh/EE 109. Introduction to the Micro/Nanofabrication Lab. *9 units (0-6-3); first, second, third terms.* Introduction to techniques of micro-and nanofabrication, including solid-state, optical, and microfluidic devices. Students will be trained to use fabrication and characterization equipment available in the applied physics micro- and nanofabrication lab. Topics include Schottky diodes, MOS capacitors, light-emitting diodes, microlenses, microfluidic valves and pumps, atomic force microscopy, scanning electron microscopy, and electron-beam writing. Instructor: Staff.

APh 110. Topics in Applied Physics. *2 units (2-0-0); first, second terms.* A seminar course designed to acquaint advanced undergraduates and first-year graduate students with the various research areas represented in the option. Lecture each week given by a different member of the APh faculty, who will review their field of research. Graded pass/fail. Instructor: Bellan.

APh/Ph 112. Stochastic Resonance Phenomena and the Essential Role of Noise. *9 units (3-0-6); third term. Prerequisites: Ph 12 abc, ACM 95/100 ab and Ph 106 abc, equivalent background, or instructor's permission.* Noise is often regarded as a nuisance. In experimental systems, it diminishes signal to noise ratio and obfuscates patterns and weak signals. In theoretical systems, it requires modelling by stochastic differential equations, whose solutions can be analytically intractable except for the simplest of Gaussian processes. Research on classical and quantum systems has revealed, however, that noise is essential when boosting hidden signatures by the phenomenon known as stochastic resonance. Many different methods proposed for inducing stochastic resonance are now revolutionizing measurement and modeling in fields as wide ranging as nonlinear optics and photonics, quantum communication, SQUID devices, neurophysiology, hydrodynamics, climate research and finance. This course, designed to appeal to theorists and experimentalists alike, is conducted in survey and seminar style. Review of the current literature will be complimented by lectures and readings focused on statistical physics and stochastic processes. Instructor: Troian.

APh 114 abc. Solid-State Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 125 abc or equivalent.* Introductory lecture and problem course dealing with experimental and theoretical problems in solid-state physics. Topics include crystal structure, symmetries in solids, lattice vibrations, electronic states in solids, transport phenomena, semiconductors, superconductivity, magnetism,

ferroelectricity, defects, and optical phenomena in solids. Instructors: Nadj-Perge, Schwab.

Ph/APh/EE/BE 118 ab. Physics of Measurement. *9 units (3-0-6);* For course description, see Physics

Ph/APh/EE 118 c. Physics of Measurement: Moonbounce and Beyond - Microwave Scattering for Communications and Metrology. *9 units (3-0-6);* For course description, see Physics

APh 119. Nanofabrication Techniques. *6 units (1-4-1); third term. Prerequisites: students are encouraged to take APh/EE 9 or APh/EE 109 ahead of this class, but these are not required.* This laboratory/lecture course will enable students to become proficient in micro- and nanofabrication and get trained on most of the instruments in Caltech's Kavli Nanoscience Institute cleanroom. Students will learn the capabilities and limitations of nanofabrication equipment, followed by training on these nanofabrication instruments in the KNI cleanroom facility. Instructor: Scherer.

EE/APh 120. Physical Optics. *9 units (3-0-6);* For course description, see Electrical Engineering

MS/APh 122. Diffraction, Imaging, and Structure. *9 units (0-4-5);* For course description, see Materials Science

EE/APh 123. Advanced Lasers and Photonics Laboratory. *9 units (1-3-5);* For course description, see Electrical Engineering

APh/EE 130. Electromagnetic Theory for Photonic Devices. *9 units (3-0-6); first term.* This course introduces the theoretical formalism required to model passive and nonlinear photonic devices. Topics include: propagation of electromagnetic fields in isotropic and anisotropic media, polarization states and their representations, optical rays, optical beams, guided waves in dielectric slabs and fibers, optical resonators, introduction to nonlinear optics, second harmonic generation, quasi-phase matching, electro-optic effects. Instructor: Faraon.

APh/EE 131. Light Interaction with Atomic Systems-Lasers. *9 units (3-0-6); second term. Prerequisites: APh/EE 130.* Light-matter interaction, spontaneous and induced transitions in atoms and semiconductors. Absorption, amplification, and dispersion of light in atomic media. Principles of laser oscillation, generic types of lasers including semiconductor lasers, mode-locked lasers. Frequency combs in lasers. The spectral properties and coherence of laser light. Instructor: Vahala.

APh/EE 132. Special Topics in Photonics and Optoelectronics. *9 units (3-0-6); third term.* Interaction of light and matter, spontaneous and stimulated emission, laser rate equations, mode-locking, Q-switching,

semiconductor lasers. Optical detectors and amplifiers; noise characterization of optoelectronic devices. Propagation of light in crystals, electro-optic effects and their use in modulation of light; introduction to nonlinear optics. Optical properties of nanostructures. Not offered 2025-26.

Ph/APh 137 ab. Atoms and Photons. *9 units (3-0-6);* For course description, see Physics

APh/Ph 138 ab. Quantum Hardware and Techniques. *9 units (3-0-6); third term, a and b offered in alternating years. Prerequisites: Ph 125 abc or Ph 127 ab or Ph 137 ab or instructor's permission.* This class covers multiple quantum technology platforms and related theoretical techniques, and will provide students with broad knowledge in quantum science and engineering. It will be split into modules covering various topics including solid state quantum bits, topological quantum matter, trapped atoms and ions, applications of near-term quantum computers, superconducting qubits. Topics will alternate from year to year. Instructors: Faraon, Minnich.

APh/MS 141. Introduction to Computational Methods for Science and Engineering. *9 units (3-0-6); third term. Prerequisites: graduate standing or instructor's permission.* A broad introduction to scientific computing using Python. Introduction to Python and its packages Numpy, SciPy, and Matplotlib. Numerical precision and sources of error. Root-finding and optimization. Numerical differentiation and integration. Introduction to numerical methods for linear systems and eigenvalue problems. Numerical methods for ordinary differential equations. Finite-difference methods for partial differential equations. Discrete Fourier transform. Introduction to data-driven and machine learning methods, including deep learning using Keras and Tensorflow. Introduction to quantum computing using Qiskit and IBM-Q. Students develop numerical calculations in the homework and in midterm and final projects. Instructor: Bernardi.

EE/APh 149. Frontiers of Nonlinear Photonics. *9 units (3-0-6);* For course description, see Electrical Engineering

APh 150. Topics in Applied Physics. *Units and terms to be arranged;* Content will vary from year to year, but at a level suitable for advanced undergraduate or beginning graduate students. Topics are chosen according to the interests of students and staff. Visiting faculty may present portions of this course.

APh/Ph/MS 152. Fundamentals of Fluid Flow in Small Scale Systems. *9 units (3-0-6); second term. Prerequisites: ACM 95/100 ab or equivalent.* Research efforts in many areas of applied science and engineering are increasingly focused on microsystems involving active or passive fluid flow confined to 1D, 2D or 3D platforms. Intrinsically large ratios of surface to volume can incur unusual surface forces and boundary effects essential to operation of microdevices for applications such as

optofluidics, bioengineering, green energy harvesting and nanofilm lithography. This course offers a concise treatment of the fundamentals of fluidic behavior in small scale systems. Examples will be drawn from pulsatile, oscillatory and capillary flows, active and passive spreading of liquid dots and films, thermocapillary and electrowetting systems, and instabilities leading to self-sustaining patterns. Students must have working knowledge of vector calculus, ODEs, basic PDEs, and complex variables. Not offered 2025-26. Instructor: Troian.

APh/Ph/Ae/MS 153. Fundamentals of Energy and Mass Transport in Small Scale Systems. *9 units (3-0-6); third term. Prerequisites: ACM 95/100 ab or equivalent.* The design of instrumentation for cooling, sensing or measurement in microsystems requires special knowledge of the evolution and propagation of thermal and concentration gradients in confined geometries, which ultimately control the degree of maximum energy and mass exchange. A significant challenge facing the microelectronics industry, for example, is mitigation of hot spots in densely packed high power chips for artificial intelligence to prevent thermal runaway. This course offers a concise treatment of the fundamentals of mass and energy transport by examining steady and unsteady diffusive and convective processes in small confined systems. Contrasts with macroscale behavior caused by the effects of small scale confinement and reduced dimensionality will be examined. Sample problems will be drawn from systems in applied physics, material science, electrical and bioengineering. Students must have working knowledge of vector calculus, ODEs, basic PDEs, and complex variables. Not offered 2025-26. Instructor: Troian.

APh 156 abc. Plasma Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 106 abc or equivalent.* An introduction to the principles of plasma physics. A multitiered theoretical infrastructure will be developed consisting of the Hamilton-Lagrangian theory of charged particle motion in combined electric and magnetic fields, the Vlasov kinetic theory of plasma as a gas of interacting charged particles, the two-fluid model of plasma as interacting electron and ion fluids, and the magnetohydrodynamic model of plasma as an electrically conducting fluid subject to combined magnetic and hydrodynamic forces. This infrastructure will be used to examine waves, transport processes, equilibrium, stability, and topological self-organization. Examples relevant to plasmas in both laboratory (fusion, industrial) and space (magneto-sphere, solar) will be discussed. Instructor: Bellan.

EE/APh 158. Quantum Electrical Circuits. *9 units (3-0-6);* For course description, see Electrical Engineering

BE/Bi/APh 161. Physical Biology of the Cell. *12 units (3-0-9);* For course description, see Bioengineering

MS/APh 162. Electronic Structure of Materials. *9 units (3-0-6);* For course description, see Materials Science

MS/APh 171. Inelastic Scattering of Materials, Molecules, and Condensed Matter. *9 units (3-0-6);* For course description, see Materials Science

EE/APh 180. Nanotechnology. *6 units (3-0-3);* For course description, see Electrical Engineering

APh/EE 183. Physics of Semiconductors and Semiconductor Devices. *9 units (3-0-6); third term.* Principles of semiconductor electronic structure, carrier transport properties, and optoelectronic properties relevant to semiconductor device physics. Fundamental performance aspects of basic and advanced semiconductor electronic and optoelectronic devices. Topics include energy band theory, carrier generation and recombination mechanisms, quasi-Fermi levels, carrier drift and diffusion transport, quantum transport. Instructor: Nadj-Perge.

APh/EE 190 abc. Quantum Electronics. *9 units (3-0-6); second, third terms. Prerequisites: Ph 125 or equivalent.* Generation, manipulations, propagation, and applications of coherent radiation. The basic theory of the interaction of electromagnetic radiation with resonant atomic transitions. Laser oscillation, important laser media, Gaussian beam modes, the electro-optic effect, nonlinear-optics theory, second harmonic generation, parametric oscillation, stimulated Brillouin and Raman scattering. Other topics include light modulation, diffraction of light by sound, integrated optics, phase conjugate optics, and quantum noise theory. Not offered 2025-26.

APh 200. Applied Physics Research. *Units in accordance with work accomplished;* Offered to graduate students in applied physics for research or reading. Students should consult their advisers before registering. Graded pass/fail.

Ae/ME/APh 218. Statistical Mechanics. *9 units (3-0-6);* For course description, see Aerospace

Ph/APh 223 ab. Advanced Condensed-Matter Physics. *9 units (3-0-6);* For course description, see Physics

APh 250. Advanced Topics in Applied Physics. *Units and term to be arranged;* Content will vary from year to year; topics are chosen according to interests of students and staff. Visiting faculty may present portions of this course. Instructor: Staff.

APh/MS 256. Computational Solid State Physics and Materials Science. *9 units (3-3-3); third term. Prerequisites: Ph 125 or equivalent and APh 114 ab or equivalent.* The course will cover first-principles computational methods to study electronic structure, lattice vibrations, optical properties, and charge and heat transport in materials. Topics include: Theory and practice of Density Functional Theory (DFT) and the total-energy pseudopotential method. DFT calculations of total energy, structure, defects, charge density, bandstructures, density of states,

ferroelectricity and magnetism. Lattice vibrations using the finite-difference supercell and Density Functional Perturbation Theory (DFPT) methods. Electron-electron interactions, screening, and the GW method. GW bandstructure calculations. Optical properties, excitons, and the GW-Bethe Salpeter equation method. Ab initio Boltzmann transport equation (BTE) for electrons and phonons. Computations of heat and charge transport within the BTE framework. If time permits, selected advanced topics will be covered, including methods to treat vander Waals bonds, spin-orbit coupling, correlated materials, and quantum dynamics. Several laboratories will give students direct experience with running first-principles calculations. Not offered 2025-26. Instructor: Bernardi.

APh 300. Thesis Research in Applied Physics. *Units in accordance with work accomplished;* APh 300 is elected in place of APh 200 when the student has progressed to the point where their research leads directly toward a thesis for the degree of Doctor of Philosophy. Approval of the student's research supervisor and department adviser or registration representative must be obtained before registering. Graded pass/fail.

ASTROPHYSICS

Ay 1. The Evolving Universe. *9 units (3-1-5); third term.* Introduction to modern astronomy that will illustrate the accomplishments, techniques, and scientific methodology of contemporary astronomy. The course will be organized around a set of basic questions, showing how our answers have changed in response to fresh observational discoveries. Topics to be discussed will include telescopes, stars, planets, the search for life elsewhere in the universe, supernovae, pulsars, black holes, galaxies and their active nuclei, and Big Bang cosmology. A field trip to Palomar Observatory will be organized. Not offered on a pass/fail basis. Instructor: Djorgovski.

FS/Ay 3. First-Year Seminar: Automating Discovering the Universe. *6 units (2-0-4);* For course description, see First-Year Seminars

Ay 7. Introduction to Amateur Astronomy and Astrophotography. *6 units (3-3-0);* Intended for first-year undergraduate students, this hands-on astronomy course takes place exclusively during a weekly evening session where students operate amateur-class telescopes from Caltech campus. Students will learn and gain intuition for the night sky, and will learn to align and operate small, portable telescopes to find, sketch, and calculate properties of planets and deep-sky objects. Students will also learn to operate astrophotography cameras, and will obtain and process data to produce high-quality astronomical images. The class will occasionally have a brief lecture component to support the telescope work, which will also take place during the scheduled evening sessions. Not offered 2025-26. .

Ge/Ay 11 c. Introduction to Earth and Planetary Sciences: Planetary Sciences. *9 units (3-0-6);* For course description, see Geology

Ay 20. Basic Astronomy and the Galaxy. *9 units (3-1-5); first term. Prerequisites: Ma 1 abc and Ph 1 abc, or instructor's permission.* The electromagnetic spectrum; ground and space observing techniques; telescopes and basic astrophysical optics; orbits, binary stars and exoplanets; stellar masses and radii, distances, and motions; basic radiative transfer; the HR diagram; the birth, structure, evolution, and death of stars; the structure, contents, and dynamics of the Galaxy. A term project involving the Palomar 60" telescope will introduce astronomical measurement techniques. Instructor: Mawet.

Ay 21. Galaxies and Cosmology. *9 units (3-0-6); second term. Prerequisites: Ma 1 abc, Ph 1 abc or instructor's permission.* Cosmological models and parameters, extragalactic distance scale, cosmological tests; constituents of the universe, dark matter, and dark energy; thermal history of the universe, cosmic nucleosynthesis, recombination, and cosmic microwave background; formation and evolution of structure in the universe; galaxy clusters, large-scale structure and its evolution; galaxies, their properties and fundamental correlations; formation and evolution of galaxies, star formation history of the universe; quasars and other active galactic nuclei, and their evolution; structure and evolution of the intergalactic medium; diffuse extragalactic backgrounds; the first stars, galaxies, and the reionization era. Instructor: Steidel.

Ay 30. Introduction to Modern Research. *3 units (2-0-1); first term.* Open to declared Ay majors. At the discretion of the instructor, nonmajors who have taken astronomy courses may be admitted. Course is intended for sophomores and juniors. This weekly seminar-style discussion is held in faculty homes in the evening, and is designed to encourage student communication skills as they are introduced to faculty members and their research. Each week a student will review a popular-level article or general topic in astronomy for the class. Fulfills the Institute oral scientific communications requirement. Graded pass/fail. Instructor: Howard.

Ay 31. Writing in Astronomy. *3 units (1-0-2); second term.* This course is intended to provide practical experience in the types of writing expected of professional astronomers. Example styles include: research proposals, topical reviews, professional journal manuscripts, and articles for broader audiences such as popular level magazines like Astronomy or Sky and Telescope. Each student will adopt one of these formats in consultation with the course instructor and write an original piece. An outline and several drafts reviewed by both a faculty mentor familiar with the topic and the course instructor are required. This course is most suitable for juniors and seniors. Fulfills the Institute written scientific communications requirement. Instructor: Hallinan.

Ay 43. Reading in Astronomy and Astrophysics. *Units in accordance with work accomplished, not to exceed 3;* Course is intended for students with a definite independent reading plan or who attend regular (biweekly) research and literature discussion groups. Instructor's permission required. Graded pass/fail. Instructor: Staff.

Ay 78 abc. Senior Thesis. *9 units; Prerequisites: To register, student must obtain approval of the astronomy option representative and the prospective thesis adviser.* Previous SURF or independent study work can be useful experience. Course open to senior astronomy majors only. Research must be supervised by a faculty member. Students wishing assistance in finding an adviser and/or a topic for a senior thesis are invited to consult with the astronomy option representative. The student will work with an adviser to formulate a research project, conduct original research, present new results, and evaluate them in the context of previously published work in the field. In the first term, the student should be fully engaged in, and make significant progress on, the research project. In the second term, the research continues and an outline of the thesis itself should be reviewed with the adviser and the option representative. In the third term, research work continues to completion and the focus turns to thesis writing. A thesis document of 20-100 pages must be completed and approved by the adviser and the option representative before the end of third term. The student and advisor should maintain good communication regarding the scope, content, draft due dates, and final copy of the thesis. First two terms are graded pass/fail, with grades for all three terms updated at the end of the course to the final letter grade earned after thesis submission. Instructor: Staff.

Ay 101. Physics of Stars. *9 units (3-0-6); first term. Prerequisites: Ay 20 is recommended. Ph 2 abc or Ph 12 abc is recommended.* Physics of stellar interiors and stellar atmospheres. Stellar structure including nucleosynthesis in the cores of stars and energy transport. Stellar evolution. Fundamental properties of stars. The H-R diagram. Stellar spectra, radiative transfer, and spectral line formation. Additional topics may include: stellar oscillations, rotation, mass loss, binary evolution. Instructor: Hillenbrand.

Ay 102. Physics of the Interstellar Medium. *9 units (3-0-6); second term. Prerequisites: Ay 20 is recommended. Ph 2 abc or Ph 12 abc is recommended.* An introduction to observations of the interstellar medium and relevant physical processes. Phases of the gaseous interstellar medium. Thermal balance in neutral and ionized gas. Molecular gas and star formation. Hot ionized gas. Structure and hydrodynamic evolution of ISM regions near massive stars; supernovae shocks. Global models for the interstellar medium. Interstellar and circumstellar dust. Instructor: Hopkins.

Ay/Ph 104. Relativistic Astrophysics. *9 units (3-0-6); third term. Prerequisites: Ph 1, Ph 2 ab.* This course is designed primarily for junior and senior undergraduates in astrophysics and physics. It covers the

physics of black holes and neutron stars, including accretion, particle acceleration and gravitational waves, as well as their observable consequences: (neutron stars) pulsars, magnetars, X-ray binaries, gamma-ray bursts; (black holes) X-ray transients, tidal disruption and quasars/active galaxies and sources of gravitational waves. White dwarf physics. Instructor: Phinney.

Ay 105. Optical Astronomy Instrumentation Lab. *9 units (1-5-3); third term. Prerequisites: Ay 20.* An opportunity for astronomy and physics undergraduates (juniors and seniors) to gain firsthand experience with the basic instrumentation tools of modern optical and infrared astronomy. The 10 weekly lab experiments include radiometry measurements, geometrical optics, polarization, optical aberrations, spectroscopy, CCD characterization, vacuum and cryogenic technology, infrared detector technology, adaptive optics (wavefront sensors, deformable mirrors, closed loop control) and a coronography tutorial. Instructor: Hallinan.

Ay/Ge 107. Introduction to Astronomical Observation. *12 units (2-2-8); third term. Prerequisites: CS 1 or equivalent coding experience recommended.* This hands-on, project-based course covers the design, proposal, and execution of astronomical observations, the basics of data reduction and analysis, and interacting with astronomical survey catalogs. The scope of the course includes imaging and spectroscopic observational techniques at optical and infrared wavelengths. The format centers on projects and practical skills but also includes a lecture and problem set component to establish the theoretical underpinnings of the practical work. Specific course components include: (a) Students will learn to use small, portable telescopes and find and image objects of interest using finder charts; (b) Students will build basic data reduction pipelines for imaging and spectroscopy data to understand how these types of data are used to derive scientific results; (c) Students will use Palomar Observatory to propose and execute their own research projects focused on astrophysical or planetary topics; (d) Students will query and work with data from on-line archives and catalogs. The class meets twice a week during the daytime plus one weekly evening telescope session, and has a required field trip to Palomar Observatory. Students interested in enrolling should review the logistical information on this page and ensure their schedule allows attendance of all course components prior to registering: https://dekleer.caltech.edu/ayge107. Enrollment is limited. Instructors: Hillenbrand, de Kleer.

Ay 111 abc. Introduction to Current Astrophysics Research. *1 unit (1-0-0); first, second terms.* This course is intended primarily for first-year Ay graduate students, although participation is open and encouraged. Students are required to attend seminar-style lectures given by astrophysics faculty members and other researchers. The intent of the course is for students to gain an understanding of the breadth of astrophysics research that is conducted at Caltech, and to learn about potential research opportunities, as well as different career paths in astronomy. Credit is also given for attending the weekly astronomy

colloquia. At the end of each term, students are required to summarize in oral or written form (at the discretion of the instructor), one of the covered subjects that drew their interest. Part c not offered 2025-26. Instructors: Djorgovski, El-Badry.

Ge/Ay 117. Bayesian Statistics and Data Analysis. *9 units (3-0-6);* For course description, see Geology

Ay 119. Astroinformatics. *6 units (3-0-3); third term.* This class is an introduction to the data science skills from the applied computer science, statistics, and information technology, that are needed for a modern research in any data-intensive field, but with a special focus on the astronomical applications. Open to graduate and upper-division on undergraduate students in all options. The topics covered include best programming practices, supervised and unsupervised machine learning, feature selection, dimensionality reduction, databases, Bayesian statistics, time series analysis, deep learning, data visualization, and possibly other topics. The class will feature real-world examples from cutting-edge projects in which the instructors are involved. Instructors: Djorgovski, Graham, Mahabal, Lombeyda.

Ay 121. Radiative Processes. *9 units (3-0-6); first term. Prerequisites: Ph 106 bc, Ph 125 or equivalent (undergraduates).* The interaction of radiation with matter: radiative transfer, emission, and absorption. Compton processes, coherent emission processes, synchrotron radiation, collisional excitation, spectroscopy of atoms and molecules. Instructor: Kulkarni.

Ay 122 abc. Astronomical Measurements and Instrumentation. *9 units (3-0-6); first, third terms. Prerequisites: Ph 106 bc or equivalent.* Measurement and signal analysis techniques throughout the electromagnetic spectrum. Courses may include lab work and field trips to Caltech observatories. Ay 122 a concentrates on infrared, optical, and ultraviolet techniques: telescopes, optics, detectors, photometry, spectroscopy, active/adaptive optics, coronography. Imaging devices and image processing. Ay 122 b concentrates on radio through submillimeter techniques: antennae, receivers, mixers, and amplifiers. Interferometers and aperture synthesis arrays. Signal analysis techniques and probability and statistics, as relevant to astronomical measurement. Ay 122 c concentrates on X-ray through gamma-ray techniques. Part b not offered 2025-26. Instructors: Howard, Kasliwal, Ravi.

Ay 123. Structure and Evolution of Stars. *9 units (3-0-6); first term. Prerequisites: Ay 101; Ph 125 or equivalent (undergraduates).* Thermodynamics, equation of state, convection, opacity, radiative transfer, stellar atmospheres, nuclear reactions, and stellar models. Evolution of low- and high-mass stars, supernovae, and binary stars. Instructor: Fuller.

Ay 124. Structure and Evolution of Galaxies. *9 units (3-0-6); second term. Prerequisites: Ay 21; Ph 106 or equivalent (undergraduates).* Stellar dynamics and properties of galaxies; instabilities; spiral and barred galaxies; tidal dynamics and galaxy mergers; stellar composition, masses, kinematics, and structure of galaxies; galactic archeology; galactic star formation; feedback from stars and super-massive black holes; circum-galactic medium. Instructor: Phinney.

Ay 125. High-Energy Astrophysics. *9 units (3-0-6); second term. Prerequisites: Ph 106 and Ph 125 or equivalent (undergraduates).* High-energy astrophysics, the final stages of stellar evolution; supernovae, binary stars, accretion disks, pulsars; extragalactic radio sources; active galactic nuclei; black holes. Instructors: Kasliwal, El-Badry.

Ay 126. Interstellar and Intergalactic Medium. *9 units (3-0-6); third term. Prerequisites: Ay 102 (undergraduates).* Physical processes in the interstellar medium. Ionization, thermal and dynamic balance of interstellar medium, molecular clouds, hydrodynamics, magnetic fields, H II regions, supernova remnants, star formation, global structure of interstellar medium. Instructor: Steidel.

Ay 127. Astrophysical Cosmology. *9 units (3-0-6); third term. Prerequisites: Ay 21; Ph 106 or equivalent (undergraduates).* Cosmology; extragalactic distance determinations; relativistic cosmological models; thermal history of the universe; nucleosynthesis; microwave background fluctuations; large-scale structure; inter-galactic medium; cosmological tests; galaxy formation and clustering. Instructor: Hopkins.

Ge/Ay 132. Atomic and Molecular Processes in Astronomy and Planetary Sciences. *9 units (3-0-6);* For course description, see Geology

Ge/Ay 133. The Formation and Evolution of Planetary Systems. *9 units (3-0-6);* For course description, see Geology

Ge/Ay 137. Planetary Physics. *9 units (3-0-6);* For course description, see Geology

Ay 141 abc. Research Conference in Astronomy. *2 units (1-0-1); first, second, third terms.* Oral reports on current research in astronomy, providing students an opportunity for practice in the organization and presentation of technical material. A minimum of two presentations will be expected from each student each year. In addition, students are encouraged to participate in a public-level representation of the same material for posting to an outreach website. This course fulfills the option communication requirement and is required of all astronomy graduate students who have passed their qualifying exam. It is also recommended for astronomy seniors; non-seniors can attend but cannot take the course for credit. Graded pass/fail. Instructors: Hillenbrand, Hallinan, Fuller.

Ay 142. Research in Astronomy and Astrophysics. *Units in accordance with work accomplished;* The student should consult a member of the department and have a definite program of research outlined. Approval by the student's adviser must be obtained before registering. 36 units of Ay 142 or Ay 143 required for candidacy for graduate students. Graded pass/fail.

Ay 143. Reading and Independent Study. *Units in accordance with work accomplished;* The student should consult a member of the department and have a definite program of reading and independent study outlined. Approval by the student's adviser must be obtained before registering. 36 units of Ay 142 or Ay 143 required for candidacy for graduate students. Graded pass/fail.

Ay 144. Independent Writing in Astronomy. *3 units (0-0-3); offered every term. Prerequisites: Ay 142.* This course is intended to be taken by students conducting minor study in the Ay option, subsequent to a term of Ay 142 (Research in Astronomy and Astrophysics), or by students who have completed a SURF with an astronomy faculty member and are writing it up for publication. Students should sign up in the section of the faculty member who supervised the research project. Course requirements are (at minimum) bi-weekly meetings with the research adviser and preparation of a 5-20 page write-up of the work in the style of one of the major journals, such as ApJ/AJ or Science/Nature. This course is required as part of the Ay minor. Instructor: Staff.

Ge/Ay 159. Astrobiology. *9 units (3-0-6);* For course description, see Geology

Ay 190. Computational Astrophysics. *9 units (3-0-6); third term. Prerequisites: Ph 20-22 (undergraduates).* Introduction to essential numerical analysis and computational methods in astrophysics and astrophysical data analysis. Basic numerical methods and techniques; N-body simulations; fluid dynamics (SPH/grid-based); MHD; radiation transport; reaction networks; data analysis methods; numerical relativity. Not offered 2025-26.

Ay/Ge 198. Special Topics in the Planetary Sciences. *6 units (2-0-4); third term.* Topic for 2024-25 is Extrasolar Planets. Thousands of planets have been identified in orbit around other stars. Astronomers are now embarking on understanding the statistics of extrasolar planet populations and characterizing individual systems in detail, namely star-planet, planet-planet and planet-disk dynamical interactions, physical parameters of planets and their composition, weather phenomena, etc. Direct and indirect detection techniques are now completing the big picture of extra-solar planetary systems in all of their natural diversity. The seminar-style course will review the state of the art in exoplanet science, take up case studies, detail current and future instrument needs, and anticipate findings. Instructor: Howard.

Ay 211. Contemporary Extragalactic Astronomy. *9 units (3-0-6); first term. Prerequisites: Ay 123, Ay 124, and Ay 127.* Topics in extragalactic astronomy and cosmology, including observational probes of dark matter and dark energy; cosmological backgrounds and primordial element abundances; galaxy formation and evolution, including assembly histories, feedback and environmental effects; physics of the intergalactic medium; the role of active galactic nuclei; galactic structure and stellar populations; future facilities and their likely impact in the field. Not offered 2025-26.

Ay 215. Seminar in Theoretical Astrophysics. *9 units (3-0-6); third term.* Course for graduate students and seniors in astronomy. Topic for 2022-23 will be compact binaries containing white dwarfs, neutron stars and black holes. Formation, mass transfer, accretion, X-ray and pulsar binaries, magnetic and wind interactions, mergers, gravitational waves. Students will be required to lead some discussions; homework will consist exclusively of reading and working through selected papers in preparation for discussions. Instructor: Kulkarni.

Ay 218. Extrasolar Planets. *9 units (3-0-6); third term.*

Ay 219. Elements in the Universe and Galactic Chemical Evolution. *9 units (3-0-6); second term. Prerequisites: Ay 121, 123, 124, 126.* Survey of the formation of the elements in the universe as a function of cosmic time. Review of the determination of abundances in stars, meteorites, H II regions, and in interstellar and intergalactic gas. Overview of models of galactic chemical evolution. Participants will measure elemental abundances from the Keck spectrum of a star and construct their own numerical chemical evolution models. Not offered 2025-26.

BIOCHEMISTRY & MOLECULAR BIOPHYSICS

Bi/BE/BMB 115. Viruses and Applications to Biological Systems. *9 units (3-2-4);* For course description, see Biology

Ch/BMB 129. Introduction to Biophotonics. *9 units (3-0-6);* For course description, see Chemistry

BMB/Bi/Ch 170. Biochemistry and Biophysics of Macromolecules and Molecular Assemblies. *9 units (3- 0-6); Prerequisites: Ch/Bi 110.* Detailed analysis of the structures of the four classes of biological molecules and the forces that shape them. Introduction to molecular biological and visualization techniques. Not offered 2025-26.

BMB/Bi/Ch 173. Biophysical/Structural Methods. *9 units (3-0-6); third term.* Basic principles of modern structural and biophysical methods used to interrogate macromolecules from the atomic to cellular levels,

including light and electron microscopy, X-ray crystallography, single molecule spectroscopy and microscopy techniques, and molecular dynamics and systems biology simulations. Instructor: Chong.

BMB/Bi/Ch 174. Macromolecular Machines of the Central Dogma. *6 units (3-0-3); first term. Prerequisites: Ch/Bi 110 ab or equivalent.* The central dogma of molecular biology describes the flow of genetic information from DNA to RNA to protein. Each step in this process depends on different macromolecular machines that copy, transcribe, and decode the information stored in DNA. This course will focus on the function of such assemblies, including the replisome, RNA Pol II, the spliceosome, the ribosome, and translocons. The course will be taught through a combination of lectures and student-led discussions of the primary literature that has shaped our understanding of how macromolecular machines operate. Students will also prepare a short research proposal that will be peer reviewed and discussed at the end of the term at a mock NIH-style study section. Instructor: Semlow.

BMB/Ch 178. Macromolecular Function: kinetics, energetics, and mechanisms. *9 units (3-0-6); second term. Prerequisites: Ch/Bi 110a or equivalent.* Discussion of the energetic principles and molecular mechanisms that underlie enzyme's catalytic proficiency and exquisite specificity. Principles of selectivity, allostery, and force generation in biology. Practical kinetics and their application to more complex biological systems, including steady-state and pre-steady-state kinetics, and kinetic simulations. Instructor: Shan.

Bi/BMB 189. The Cell Cycle and Genomic Stability. *6 units (2-0-4);* For course description, see Biology

BMB/Ch 202 abc. Biochemistry Seminar Course. *1 unit; first, second, third terms. Prerequisites: Graduate students only. Undergrads require special instructor permission to enroll.* The course focuses on a seminar on selected topics from outside faculty on recent advances in biochemistry. Components for each faculty visit include participation in a recitation, a formal discussion section with visiting faculty, and attendance of the Biochemistry seminar. Biochemistry Seminars take place 1-2 times per month (usually 4pm on Thursdays). Instructor: Shan.

Bi/BE/BMB 222. The Structure of the Cytosol. *6 units (2-0-4);* For course description, see Biology

BMB/Ch 230. Macromolecular Structure Determination with Modern X-ray Crystallography Methods. *12 units (2-4-6); third term. Prerequisites: Consent of instructor.* Advanced course in macromolecular crystallography integrating lecture and laboratory treatment of diffraction theory, crystallization (proteins, nucleic acids and macromolecular complexes), crystal characterization, X-ray sources and optics, crystal freezing, X-ray diffraction data collection (in-house and synchrotron), data reduction, multiple isomorphous replacement, single- and multi-wavelength anomalous diffraction phasing techniques,

molecular replacement, electron density interpretation, structure refinement, structure validation, coordinate deposition and structure presentation. In the laboratory component, one or more proteins will be crystallized and the structure(s) determined by several methods, in parallel with lectures on the theory and discussions of the techniques. Instructor: Hoelz.

Bi/BMB 251 abc. Current Research in Biology and Biological Engineering. *1 unit;* For course description, see Biology

BMB 299. Graduate Research. *Units to be arranged; first, second, third terms.* Students may register for research units after consultation with their adviser.

BIOENGINEERING

BE 1. Frontiers in Bioengineering. *1 unit; first term.* A weekly seminar series by Caltech faculty providing an introduction to research directions in the field of bioengineering and an overview of the courses offered in the Bioengineering option. Graded pass/fail. Instructor: Bois.

Bi/BE 24. Scientific Communication for Biological Scientists and Engineers. *6 units (3-0-3);* For course description, see Biology

BE/Bi 25. Biophysical Chemistry. *9 units (3-0-6); second term. Prerequisites: Ch 1 ab, Ma 2.* This course develops principles of solution thermodynamics, chemical kinetics, and transport processes applied to living systems. Instructor: Bois.

BE 98. Undergraduate Research in Bioengineering. *Variable units, as arranged with the advising faculty member; first, second, third terms.* Undergraduate research with a written report at the end of each term; supervised by a Caltech faculty member, or co-advised by a Caltech faculty member and an external researcher. Graded pass/fail. May not be taken after BE 99. Instructor: Staff.

BE 99 abc. Senior Thesis in Bioengineering. *6 or more units per term with a three-term total of at least 27 units; first, second, third terms. Prerequisites: Junior or senior standing and instructor's permission.* Research in Bioengineering, supervised by a Caltech faculty member, culminating in a thesis. The topic is determined by the research adviser and the student and is subject to approval by the Bioengineering faculty. The first and second terms are taken pass/fail and require a written report at the end of each term. The third term is taken on grades and requires completion of a thesis and final presentation. The last two terms must be completed in the final year of study. Total units arranged with the advising faculty member. Instructor: Staff.

BE/Bi 103 a. Introduction to Data Analysis in the Biological Sciences. *9 units (1-3-5); first term. Prerequisites: Bi 1 or equivalent; CS 1, BE/Bi/NB 203, or equivalent; or instructor's permission.* This course covers tools needed to analyze quantitative data in biological systems. Students learn basic programming topics, data organization and wrangling, data display and presentation, parameter estimation, and resampling-based statistical inference. Students analyze real data in class and in homework. Instructor: Bois.

BE/Bi 103 b. Statistical Inference in the Biological Sciences. *9 units (1-3-5); second term. Prerequisites: BE/Bi 103 a or equivalent; Ma 1 abc and Ma 3, or Bi/CNS/NB 195, or equivalent; or instructor's permission.* This course introduces students to statistical modeling and inference, primarily taking a Bayesian approach. Topics include generative modeling, parameter estimation, model comparison, hierarchical modeling, Markov chain Monte Carlo, graphical display of inference results, and principled workflows. Other topics may also be included. All techniques are applied to real biological data sets in class and in homework. Instructor: Bois.

BE 107. Exploring Biological Principles Through Bio-Inspired Design. *9 units (3-5-1); third term.* Students will formulate and implement an engineering project designed to explore a biological principle or property that is exhibited in nature. Students will work in small teams in which they build a hardware platform that is motivated by a biological example in which a given approach or architecture is used to implement a given behavior. Alternatively, the team will construct new experimental instruments in order to test for the presence of an engineering principle in a biological system. Example topics include bio-inspired control of motion (from bacteria to insects), processing of sensory information (molecules to neurons), and robustness/fault-tolerance. Each project will involve proposing a specific mechanism to be explored, designing an engineering system that can be used to demonstrate and evaluate the mechanism, and building a computer-controlled, electro-mechanical system in the lab that implements or characterizes the proposed mechanism, behavior or architecture. Not offered 2025-26. Instructors: Dickinson, Murray.

BE 111. Making Life: Genome Synthesis from Elements. *9 units (3-0-6); third term. Prerequisites: Bi 1, Bi 8, or equivalent; or instructor's permission.* Advances in life science research and biotechnology require manipulation and synthesis of DNA and DNA genomes. This course focuses on how to create DNA of increasing lengths, both synthesized in vitro and integrated in vivo. Starting from 5 natural elements (C, H, O, P, N), the course will cover technologies to make DNA from a single nucleotide to 200-nucleotide short oligos, to 1-kb individual genes, to 10-kb gene clusters, to 100-kb genomic fragments, to multi-megabase bacterial genomes, and further beyond to 50-mb mammalian chromosomes and ultimately multi-gigabase mammalian genomes. The course will also cover technologies required to amplify, sequence, and deliver these assembled DNAs ranging from the single gene to the whole

genome scale. Topics are approached from experimental, theoretical, and industrial perspective. Instructor: Wang.

ChE/BE/MedE 112. Enhancing Technical Creativity with AI Tools in the Context of Microfluidics for Global Health. *9 units (3-0-6);* For course description, see Chemical Engineering

Bi/BE/BMB 115. Viruses and Applications to Biological Systems. *9 units (3-2-4);* For course description, see Biology

Ph/APh/EE/BE 118 ab. Physics of Measurement. *9 units (3-0-6);* For course description, see Physics

Bi/BE 119. Morphogenesis of Developmental Systems. *9 units (3-0-6);* For course description, see Biology

Bi/BE 129. The Biology and Treatment of Cancer. *9 units (3-0-6);* For course description, see Biology

ChE/Ch/BE 130. Biomolecular Engineering Laboratory. *9 units (0-6-3);* For course description, see Chemical Engineering

Ge/Bi/BE/CNS/ESE 147. Challenges and Opportunities in Quantitative Ecology. *6 units (6-0-0);* For course description, see Geology

BE 150. Biological Circuit Design. *9 units (3-0-6); third term. Prerequisites: Bi 1, Bi 8, or equivalent; Ma 2, Bi/CNS/NB 195, or equivalent; or instructor's permission.* Quantitative studies of cellular and developmental systems in biology, including the architecture of specific circuits controlling microbial behaviors and multicellular development in model organisms. Specific topics include chemotaxis, multistability and differentiation, biological oscillations, stochastic effects in circuit operation, as well as higher-level circuit properties, such as robustness. The course will also consider the organization of transcriptional and protein-protein interaction networks at the genomic scale. Topics are approached from experimental, theoretical, and computational perspectives. Instructors: Bois, Elowitz.

BE 153. Case Studies in Systems Physiology. *9 units (3-0-6); third term. Prerequisites: Bi 8, Bi 9, or equivalent.* This course will explore the process of creating and validating theoretical models in systems biology and physiology. It will examine several macroscopic physiological systems in detail, including examples from immunology, endocrinology, cardiovascular physiology, and others. Emphasis will be placed on understanding how macroscopic behavior emerges from the interaction of individual components. Instructor: Petrasek.

NB/Bi/BE 155. Neuropharmacology. *6 units (3-0-3);* For course description, see Neurobiology

BE/Bi/APh 161. Physical Biology of the Cell. *12 units (3-0-9); second term. Prerequisites: Ph 2 ab and ACM 95/100 ab,or background in differential equations and statistical and quantum mechanics, or instructor's written permission..* Physical models applied to the analysis of biological structures ranging from individual proteins and DNA to entire cells. Typical topics include the force response of proteins and DNA, models of molecular motors, DNA packing in viruses and eukaryotes, mechanics of membranes, and membrane proteins and cell motility. Instructor: Bois.

BE/ChE 163. Introduction to Biomolecular Engineering. *12 units (3-0-9); first term. Prerequisites: Bi 8, or instructor's permission and CS 1 or equivalent.* The course introduces rational design and evolutionary methods for engineering functional protein and nucleic acid systems. Rational design topics include molecular modeling, positive and negative design paradigms, simulation and optimization of equilibrium and kinetic properties, design of catalysts, sensors, motors, and circuits. Evolutionary design topics include evolutionary mechanisms and tradeoffs, fitness landscapes and directed evolution of proteins. Some assignments require programming (Python is the language of instruction). Instructors: Mayo, Pierce.

MedE/EE/BE 168 abc. Biomedical Optics: Principles and Imaging. *9 units (4-0-5) each;* For course description, see Medical Engineering

Bi/BE 177. Principles of Modern Microscopy. *9 units (3-0-6);* For course description, see Biology

Bi/BE/CS 183. Introduction to Computational Biology and Bioinformatics. *9 units (3-0-6);* For course description, see Biology

ChE/BE/MedE 188. Molecular Imaging. *9 units (3-0-6);* For course description, see Chemical Engineering

BE/EE/MedE 189. Design and Construction of Biodevices. *12 units (3-6-3); first, third terms.* Students will learn to use an Arduino microcontroller to interface sensing and actuation hardware with the computer. Students will learn and practice engineering design principles through a set of projects where they design and implement biosensing systems. Examples include a pulse monitor, a pulse oximeter, and a real-time polymerase-chain-reaction incubator. Enrollment is limited based on laboratory capacity. Instructor: Russell.

BE/CS/CNS/Bi 191 ab. Biomolecular Computation. *9 units; part a (3-0-6) and part b (2-4-3); second, third terms. Prerequisites: BE/CS/CNS/Bi 191 a must be taken before BE/CS/CNS/Bi 191 b. Recommended: BE/ChE 163, CS 21, or equivalent.* This course investigates computation by molecular systems, emphasizing models of computation based on the underlying physics, chemistry, and organization of biological cells. We will explore programmability, complexity, simulation of, and reasoning about abstract models of

chemical reaction networks, molecular folding, molecular self-assembly, and molecular motors, with an emphasis on universal architectures for computation, control, and construction within molecular systems. If time permits, we will also discuss biological example systems such as signal transduction, genetic regulatory networks, and the cytoskeleton; physical limits of computation, reversibility, reliability, and the role of noise, DNA-based computers and DNA nanotechnology. Part a develops fundamental results; part b is a reading and research course: classic and current papers will be discussed, and students will do projects on current research topics. Instructor: Winfree.

BE/CS 196 ab. Design and Construction of Programmable Molecular Systems. *part a is 12 units (2-4-6) and part b is 9 units (2-4-3); part a is second term; part b is third term. Prerequisites: BE/CS 196 a must be taken before BE/CS 196 b.* This course will introduce students to the conceptual frameworks and tools of computer science as applied to molecular engineering, as well as to the practical realities of synthesizing and testing their designs in the laboratory. In part a, students will design and construct DNA circuits and self-assembled DNA nanostructures, as well as quantitatively analyze the designs and the experimental data. Students will learn laboratory techniques including fluorescence spectroscopy and atomic force microscopy and will use software tools and program in Mathematica. Part b is an open-ended design and build project requiring instructor's permission for enrollment. Limited enrollment. Part b not offered 2025-26. . Instructor: Qian.

BE/Bi/CNS/NB 197. Mentoring and Outreach. *Units to be arranged, up to 12 units per year; taken in any term, usually 3 units per term and not more than 6 in a single term.* In consultation with, and with the approval of, a faculty advisor (usually the student's academic advisor) and the Caltech Center for Teaching, Learning, and Outreach. Students may obtain credit for engaging in volunteer efforts to promote public understanding of science; to mentor and tutor young people and underserved populations; or to otherwise contribute to the diversity, equity, and inclusiveness of the scientific enterprise. Students will be required to fill out short pre- and post-outreach activity forms to describe their proposal and to report on the results. Students may petition their option representative (graduate students) or academic advisor (undergraduate students) if they seek credits beyond the 12-unit limit. Offered pass/fail. Instructor: Staff.

BE 200. Research in Bioengineering. *Units and term to be arranged;* By arrangement with members of the staff, properly qualified graduate students are directed in bioengineering research.

BE 201. Reading the Bioengineering Literature. *4 units (1-0-3); second term.* Participants will read, discuss, and critique papers on diverse topics within the bioengineering literature. Offered only for Bioengineering graduate students. Instructor: Winfree.

BE/Bi/NB 203. Introduction to Programming for the Biological Sciences Bootcamp. *6 units; summer term.* This course provides an intensive, hands-on, pragmatic introduction to computer programming aimed at biologists and bioengineers. No previous programming experience is assumed. Python is the language of instruction. Students will learn basic concepts such as data types, control structures, string processing, functions, input/output, etc., while writing code applied to biological problems. At the end of the course, students will be able to perform simple simulations, write scripts to run software packages and parse output, and analyze and plot data. This class is offered as a week-long summer "boot camp" the week after Commencement, in which students spend all day working on the course. Graded pass/fail. Instructor: Bois.

BE/Bi 205. Deep Learning for Biological Data. *9 units (3-0-6); third term. Prerequisites: BE/BI 103 a and BE/BI 103 b or equivalent; or instructor's permission. CMS/CS/CNS/EE/IDS 155 is strongly recommended but not required.* This course is a practical introduction to machine learning methods for biological data, focusing on three common data types in biology-images, sequences, and structures. This course will cover how to represent biological data in a manner amenable to machine learning approaches, survey tasks that can be solved with modern deep learning algorithms (e.g. image segmentation, object tracking, sequence classification, protein folding, etc.), explore architectures of deep learning models for each data type, and provide practical guidance for model development. Students will have the opportunity to apply these methods to their own datasets. Not offered 2025-26. Instructor: Van Valen.

Bi/BE/BMB 222. The Structure of the Cytosol. *6 units (2-0-4);* For course description, see Biology

Bi/BE 227. Methods in Modern Microscopy. *12 units (2-6-4);* For course description, see Biology

Bi/CNS/BE/NB 230. Optogenetic and CLARITY Methods in Experimental Neuroscience. *9 units (3-2-4);* For course description, see Biology

BE 240. Special Topics in Bioengineering. *Units and term to be arranged;* Topics relevant to the general educational goals of the bioengineering option. Graded pass/fail.

Bi/BE/CNS/NB 241. Spatial Genomics. *9 units (1-8-0);* For course description, see Biology

Ae/BE 242. Biological Flows: Propulsion. *9 units (3-0-6);* For course description, see Aerospace

MedE/BE/Ae 243. Physiological Mechanics. *9 units (3-0-6);* For course description, see Medical Engineering

BE 262. Physical Biology Bootcamp. *12 units (2-10-0); summer term. Prerequisites: Enrollment limited to incoming Biology, Biochemistry and Molecular Biophysics, Bioengineering, and Neurobiology graduate students, or instructor's permission.* This course provides an intensive introduction to thinking like a quantitative biologist. Every student will build a microscope from scratch, use a confocal microscope to measure transcription in living fly embryos and perform a quantitative dissection of gene expression in bacteria. Students will then use Python to write computer code to analyze the results of all of these experiments. No previous experience in coding is presumed, though for those with previous coding experience, advanced projects will be available. In addition to the experimental thrusts, students will use "street fighting mathematics" to perform order of magnitude estimates on problems ranging from how many photons it takes to make a cyanobacterium to the forces that can be applied by cytoskeletal filaments. These modeling efforts will be complemented by the development of physical models of phenomena such as gene expression, phase separation in nuclei, and cytoskeletal polymerization. Graded pass/fail. Instructor: Phillips.

BE 267. Research Topics in Bioengineering. *1 unit; first term. Prerequisites: Graduate Standing.* Introduction to current research topics in Caltech bioengineering labs. Graded pass/fail. Instructor: Cai.

BIOLOGY

Bi 1. The Great Ideas of Biology. *9 units (4-0-5); third term.* Biological processes take place at length scales ranging from that of individual protein molecules all the way to the algal blooms or rainforests that can be seen from space and over a dizzying nearly 30 orders of magnitude in time scales. This course will start by examining the biology of processes such as how plants and animals colonize oceanic islands and the physics of how animals such as wildebeest form giant herds during their year-long migration. With these wonders of the living world revealed, we will then seek to understand biological phenomena by thinking about genes and cells. May be taken pass/fail if taken in a first-year student's first year. Instructor: Phillips.

IC/Bi 1 abc. Integrated Core: Energy in Biology. *2 units (1-1-0); 4 units (2-1-1); 3 units (1-1-1);* For course description, see Integrated Core

Bi 1 b. The Biomechanics of Organismal Design. *9 units (3-0-6); second term.* Have you ever wondered how a penguin swims or why a maple seed spins to the ground? Can a flea jump as high as a kangaroo? Is spider silk really stronger than steel? This class will offer answers to these and other questions related to the mechanical design of plants and animals. The course will provide a basic introduction to how engineering principles from the fields of solid and fluid mechanics may be applied to the study of biological systems. The course emphasizes the organismal

level of complexity, although topics will also connect phenomenology at the molecular, cellular, and tissue-level scales. Topics include the physical properties of biological materials, viscoelasticity, biological pumps, muscle mechanics, neural control, and animal locomotion. May be taken pass/fail if taken in the first-year student's first year. Limited enrollment. Instructor: Dickinson.

Bi 1 c. Biology Through the Algorithmic Lens. *9 units (3-0-6); second term.* Do biological systems compute? Can we compute with biological systems? Is computer code a meaningful metaphor for genetic code? Do neural networks in biology have much to do with neural networks in computer science? In this class we will investigate these and other questions with a view towards learning about deep connections between biology and computer science that shed light on fundamental questions in biology. May be taken pass/fail if taken in a first-year student's first year. Instructor: Pachter.

Bi 1 e. Evolution of the Biosphere. *9 units (3-0-6); third term.* Evolutionary phenomena have shaped Earth's biosphere, from the structures of molecules to the dynamics of entire ecosystems. This course covers how the biosphere emerged through the actions of evolutionary processes operating over the past 3.7 billion years of Earth history. Evolutionary mechanisms acting at different scales of biological organization will be covered, including gene and protein evolution, gene family and genome evolution, cell type evolution, the evolution of developmental processes controlling morphology, neural circuit evolution and behavior, the molecular mechanisms that physiologically adapt organisms to their environments, and the origins of ecological relationships between species. At each scale, constraints and catalysts on the evolutionary process will be discussed that have led to the spectrum of living systems comprising our planet's tree of life. This course is inclusive of all biodiversity. Instructors: Parker, J.

Bi 1 i. Construction and Guidance of Biological Defense. *9 units (4-0-5); second term.* We are bombarded by biological threats from the outside, ranging from toxic particulates to epidemic viruses, and also by threats from within, like cancer. How do our bodies manage to be victorious against these threats for so many years, in most cases? Many people have some familiarity with aspects of the answers now, due to COVID-19. But how can these defense mechanisms actually work, and how can they coordinate their actions to be effective and safe? Why do they fail? This course will zoom between scales to introduce the cells that the body uses for immune defense and how they execute their roles, both system-wide and at the molecular level. A central theme will be how the system is controlled by cellular "software" reading the genetic code, by ultra-rapid evolutionary mechanisms, and by elegant cell-cell communication networks. Lectures and student presentations will be included. May be taken pass/fail if taken in a first-year student's first year. Limited enrollment. Given in alternate years; offered 2025-26. Instructor: Rothenberg.

Bi 1 m. Unifying Biology by Revealing the Foundational Principles of Life Systems. *9 units (3-0-6); second term.* Due to the development of new technologies in the 21st century, experimental and computational tools, such as the sequencing of nucleic acids, have become faster and more inexpensive. These new tools have allowed the biological sciences to use genetics and genomics to reveal the functional relationships of life forms across the biosphere as never before. The largest conceptual shift enabled by this new capacity is the discovery of the unexpected complexity of the invisible world of microbes. We have learned that their diversity dwarfs that of animals and plants, and that they underlie the health of all corners of the biosphere and its inhabitants. In addition, genomic analyses of microbes have revealed that they 'invented' almost every fundamental feature of biological systems, and that macroorganisms have primarily added nuances as they build upon these essential foundations. This course aims to provide students with a comprehensive view of the structure and function of the biosphere, from its evolutionary history to its molecular underpinnings and emergent ecological patterns. The integration of micro- and macrobiology in an introductory biology course will allow students to both focus on the fundamental principles driving life and to build a comprehensive conceptual framework for understanding biology, much as chemistry and physics did in the 20th century as they developed a long-lasting framework for their introductory courses. Instructors: McFall-Ngai, Ruby.

Bi 1 x. The Great Ideas of Biology: Exploration through Experimentation. *9 units (0-6-3); first, third terms.* Introduction to concepts and laboratory methods in biology. Molecular biology techniques and advanced microscopy will be combined to explore the great ideas of biology: the cell, the gene, evolution by natural selection, and life as chemistry. This course is intended for nonbiology majors. May be taken pass/fail if taken in a first-year student's first year. Limited enrollment. Offered third term, 2025-26. Instructor: Bois.

Bi 2. Current Research in Biology. *1 unit (1-0-0); first term.* Intended for students considering the biology option; open to first-year students. Current research in biology will be discussed, on the basis of reading assigned in advance of the discussions, with members of the divisional faculty. Graded pass/fail. Instructor: Elowitz.

Bi 8. Foundational Principles of Molecular Biology. *9 units (3-0-6); second term.* This course and its sequel, Bi 9, cover biology at the molecular and cellular levels. Bi 8 emphasizes genomic structure and the mechanisms responsible for the transmission and expression of genetic information. The focus is on the ways that the information content of the genome is translated into distinctive, cell-type specific patterns of gene expression and protein function. Assignments will include critical dissections of papers from classical and current research literature and problem sets. Instructors: Guttman, Hong.

Bi 9. Cell Biology. *9 units (3-0-6); third term. Prerequisites: Bi 8.* Continues coverage of biology at the cellular level, begun in Bi 8. Topics:

cytoplasmic structure, membrane structure and function, cell motility, and cell-cell recognition. Emphasis on both the ultrastructural and biochemical approaches to these topics. Instructors: Prober, Varshavsky.

Bi 10. Introductory Biology Laboratory. *6 units (1-3-2); third term. Prerequisites: Bi 8; designed to be taken concurrently with Bi 9.* An introduction to molecular, cellular, and biochemical techniques that are commonly used in studies of biological systems at the molecular level. Instructor: Goentoro.

Ch/Bi 11. Biochemistry Laboratory. *9 units (1-5-3);* For course description, see Chemistry

Bi 21. Undergraduate Research with Presentation. *Minimum 12 units per term (0-11-1); first, second, third terms.* Special problems involving laboratory research in biology; to be arranged with instructors before registration. Must give a public presentation reporting results of work. May be counted as advanced lab credit. May be repeated for credit. Instructor: Staff.

Bi 22. Undergraduate Research. *Units to be arranged; first, second, third terms.* Special problems involving laboratory research in biology; to be arranged with instructors before registration. Graded pass/fail. Instructor: Staff.

Bi 23. Biology Tutorials. *3 or 6 units; second term.* Small group study and discussion in depth of special areas or problems in biology or biological engineering, involving regular tutorial sections with instructors drawn from the divisional postdoctoral staff and others. Usually given winter term. To be arranged with instructors before registration. Graded pass/fail. Instructor: Prober.

Bi/BE 24. Scientific Communication for Biological Scientists and Engineers. *6 units (3-0-3); third term.* The goal of this class is to improve your ability, as scientific researchers, to communicate your research to fellow scientists both in and outside your field, as well as to the general public. Students will practice technical scientific writing in journal paper format, presentation of research to scientific communities, oral communication of research to scientists and non-scientists, and peer review of scientific communications. Fulfills the Institute scientific writing requirement. Instructor: Staff.

BE/Bi 25. Biophysical Chemistry. *9 units (3-0-6);* For course description, see Bioengineering

Bi 90 abc. Undergraduate Thesis. *12 or more units per term; first, second, third terms. Prerequisites: 18 units of Bi 22 (or equivalent research experience) in the research area proposed for the thesis, and instructor's permission.* Intended to extend opportunities for research provided by Bi 22 into a coherent individual research project, carried out

under the supervision of a member of the biology faculty. Normally involves three or more consecutive terms of work in the junior and senior years. The student will formulate a research problem based in part on work already carried out, evaluate previously published work in the field, and present new results in a thesis format. First two terms graded pass/fail; final term graded by letter on the basis of the completed thesis. Instructor: Staff.

CNS/Psy/Bi 102 a. Social and Decision Neuroscience. *9 units (3-0-6);* For course description, see Computation & Neural Systems

CNS/Psy/Bi 102 b. Social and Decision Neuroscience. *9 units (3-0-6);* For course description, see Computation & Neural Systems

BE/Bi 103 a. Introduction to Data Analysis in the Biological Sciences. *9 units (1-3-5);* For course description, see Bioengineering

BE/Bi 103 b. Statistical Inference in the Biological Sciences. *9 units (1-3-5);* For course description, see Bioengineering

Bi/Ge/ESE 105. Evolution. *12 units (3-4-5); second term. Prerequisites: Completion of Core Curriculum Courses. Maximum enrollment: 15, by application only.* The theory of evolution is arguably biology's greatest idea and serves as the overarching framework for thinking about the diversity and relationships between organisms. This course will present a broad picture of evolution starting with discussions of the insights of the great naturalists, the study of the genetic basis of variation, and an introduction to the key driving forces of evolution. Following these foundations, we will then focus on a number of case studies including the following: evolution of oxygenic photosynthesis, origin of eukaryotes, multicellularity, influence of symbiosis, the emergence of life from the water (i.e. fins to limbs), the return of life to the water (i.e. limbs to fins), diversity following major extinction events, the discovery of Archaea, insights into evolution that have emerged from sequence analysis, and finally human evolution and the impact of humans on evolution (including examples such as antibiotic resistance). A specific focus for considering these issues will be the island biogeography of the Galapagos. Given in alternate years; offered 2025-26. Instructors: Phillips, Orphan.

ChE/Ch/Bi/SEC 107. Social Media for Scientists. *9 units (3-0-6);* For course description, see Chemical Engineering

Ch/Bi 110 ab. Introduction to Biochemistry. *12 units (4-0-8);* For course description, see Chemistry

Ch/Bi 111. Biochemistry of Gene Expression. *12 units (4-0-8);* For course description, see Chemistry

Bi 114. Immunology. *9 units (3-0-6); second term. Prerequisites: Bi 8, Bi 9, Bi 122 or equivalent, and Ch/Bi 110 recommended.* The course will cover the molecular and cellular mechanisms that mediate recognition

and response in the mammalian immune system. Topics include cellular and humoral immunity, the structural basis of immune recognition, antigen presentation and processing, gene rearrangement of lymphocyte receptors, cytokines and the regulation of cellular responses, T and B cell development, and mechanisms of tolerance. The course will present an integrated view of how the immune system interacts with viral and bacterial pathogens and commensal bacteria. Given in alternate years; not offered 2025-26. Instructors: Bjorkman, Mazmanian.

Bi/BE/BMB 115. Viruses and Applications to Biological Systems. *9 units (3-2-4); third term.* Learn about viruses as fascinating biological machines, focusing on naturally-occurring and evolved variants, in silico viral vector engineering, and computational methods that include structure visualization and machine learning. This course will introduce the fundamentals in the chemistry and biology of viruses, emphasizing their engineerable properties for use in basic research and translational applications. Topics include: viruses by the numbers, mammalian and non-mammalian (plant, bacteria) viruses, enveloped vs. non-enveloped viruses, host-virus interactions, viral life cycles (replication vs. dormancy), immune responses to viruses, zoonosis, diverse mechanisms of entry and replication, the application of viruses as gene-delivery vehicles (with a focus on adeno-associated viruses or AAVs, lentiviruses, and rabies), and how to engineer viral properties for applications in basic research and gene therapy. The lectures will be complemented by short lab exercises in AAV preparation, bioinformatics and machine learning, and structure visualization. Given in alternate years; offered 2025-26. Instructors: Bjorkman, Gradinaru, Van Valen.

Bi 116. Microbial Genetics. *9 units (3-0-6); second term. Prerequisites: Bi 1, 8, 9 (or equivalent), and ESE/Bi 166.* A course on microbial genetics, emphasizing the history of the discipline as well as modern approaches. Students will be exposed to different ways of manipulating microbial genomes (primarily bacterial, but we will also cover archaea and microbial eukaryotes). The power of microbial genetics to shed light on diverse process will be discussed in a variety of contexts, ranging from environmental science to the mammalian microbiome. Given in alternate years; offered 2025-26. Instructors: Mazmanian, Newman, Ruby.

Bi 117. Developmental Biology. *9 units (3-0-6); second term. Prerequisites: Bi 8 and Bi 9.* A survey of the development of multicellular organisms. Topics will include the beginning of a new organism (fertilization), the creation of multicellularity (cellularization, cleavage), reorganization into germ layers (gastrulation), induction of the nervous system (neurulation), and creation of specific organs (organogenesis). Emphasis will be placed on the molecular mechanisms underlying morphogenetic movements, differentiation, and interactions during development, covering both classical and modern approaches to studying these processes. Instructors: Bronner, Zernicka-Goetz.

Bi/BE 119. Morphogenesis of Developmental Systems. *9 units (3-0-6); second term. Prerequisites: Bi 8 and Bi 9, or instructor's permission.* This

course explores how cells, tissues, and organs acquire their shape, with a focus on the role of mechanical forces in cell shape changes, migration, and adhesion dynamics. Key topics include chemotaxis, collective cell movement, and the interplay between adhesion and deadhesion during migration. The course will also examine the connection between cell migration and metastasis, as well as fundamental signaling principles in embryonic development across invertebrate and vertebrate species. Students will apply their learning by developing a grant proposal on a topic related to the course material as their term project. Instructor: Stathopoulos.

Bi 122. Genetics. *9 units (3-0-6); first term. Prerequisites: Bi 8 or Bi 9, or instructor's permission.* Lecture and discussion course covering basic principles of genetics. Not open to first-year undergraduate students. Instructor: Hay.

Bi/BE 129. The Biology and Treatment of Cancer. *9 units (3-0-6); second term.* The first part of the course will concern the basic biology of cancer, covering oncogenes, tumor suppressors, tumor cell biology, metastasis, tumor angiogenesis, and other topics. The second part will concern newer information on cancer genetics and other topics, taught from the primary research literature. The last part of the course will concern treatments, including chemotherapy, anti-angiogenic therapy, and immunotherapy. Given in alternate years; offered 2025-26. . Instructors: Zinn, Campbell.

Ch/Bi 145. Advanced Chemical Biology. *9 units (3-0-6);* For course description, see Chemistry

Bi 145 a. Tissue and Organ Physiology. *9 units (3-0-6); first term. Prerequisites: Bi 8, 9, Ch/Bi 110. Ch/Bi 110 may be taken concurrently.* Reviews of anatomy and histology, as well as in-depth discussion of cellular physiology. Building from cell function to tissues, the course explores human physiology in an organ-based fashion. First term topics include endocrine physiology, the autonomic nervous system, urinary physiology, and the cardiovascular system. Particular emphasis is placed on health issues and pharmaceutical therapy from both a research and a medical perspective. Instructor: Tydell.

Bi 145 b. Tissue and Organ Physiology. *9 units (3-0-6); second term. Prerequisites: Bi 145 a.* Building on the foundations of Bi 145 a, Bi 145 b will continue the exploration of human physiology incorporating anatomy and cellular physiology. Topics include muscle physiology, the skeletal system, digestive and hepatic physiology, nutrition, the respiratory system and reproductive physiology. Particular emphasis is placed on health issues and pharmaceutical therapy from both a research and a medical perspective. Instructor: Tydell.

Ge/Bi/BE/CNS/ESE 147. Challenges and Opportunities in Quantitative Ecology. *6 units (6-0-0);* For course description, see Geology

NB/Bi/CNS 150. Introduction to Neuroscience. *10 units (4-0-6);* For course description, see Neurobiology

NB/Bi/CNS 152. Neural Circuits and Physiology of Homeostatic Regulation. *6 units (2-0-4);* For course description, see Neurobiology

NB/Bi/CNS 154. Principles of Neuroscience. *9 units (3-0-6);* For course description, see Neurobiology

NB/Bi/BE 155. Neuropharmacology. *6 units (3-0-3);* For course description, see Neurobiology

Bi/CNS 158. Vertebrate Evolution. *9 units (3-0-6); third term. Prerequisites: Bi 1, Bi 8, or instructor's permission.* An integrative approach to the study of vertebrate evolution combining comparative anatomical, behavioral, embryological, genetic, paleontological, and physiological findings. Special emphasis will be given to: (1) the modification of developmental programs in evolution; (2) homeostatic systems for temperature regulation; (3) changes in the life cycle governing longevity and death; (4) the evolution of brain and behavior. Letter grades only. Given in alternate years; offered 2026-27. Instructor: Allman.

Bi 160. Molecular Basis of Animal Evolution. *9 units (3-3-3); third term. Prerequisites: Bi 8 and/or Bi 9 recommended.* We share the planet with well over 1.5 million other animal species. This course covers how the staggering diversity of the animal kingdom came about through underlying molecular evolutionary phenomena, including gene and protein sequence evolution, gene family and genome evolution, the evolution of developmental processes, neural circuit evolution and behavior, and molecular mechanisms that physiologically adapt animals to their environment. Molecular processes involved in speciation will be explained, together with an analysis of constraints and catalysts on the production of selectable variation that have shaped the evolution of animal life. Participants will undertake a laboratory project on evolutionary genomics, involving fieldwork, genome sequencing and comparative genome analysis. The course focuses on the >99.9% of animals that lack backbones. Not offered 2025-26. Instructor: Parker.

BE/Bi/APh 161. Physical Biology of the Cell. *12 units (3-0-9);* For course description, see Bioengineering

NB/Bi/CNS 162. Cellular and Systems Neuroscience Laboratory. *12 units (2-4-6);* For course description, see Neurobiology

NB/Bi/CNS 163. The Biological Basis of Neural Disorders. *6 units (3-0-3);* For course description, see Neurobiology

NB/Bi/CNS 164. Tools of Neurobiology. *9 units (3-0-6);* For course description, see Neurobiology

ESE/Bi 166. Microbial Physiology. *9 units (3-1-5);* For course description, see Environmental Science & Engineering

Pl/CNS/NB/Bi/Psy 167. Consciousness. *9 units (3-0-6);* For course description, see Philosophy

ESE/Bi 168. Microbial Metabolic Diversity. *9 units (3-0-6);* For course description, see Environmental Science & Engineering

BMB/Bi/Ch 170. Biochemistry and Biophysics of Macromolecules and Molecular Assemblies. *9 units (3- 0-6);* For course description, see Biochemistry & Molecular Biophysics

BMB/Bi/Ch 173. Biophysical/Structural Methods. *9 units (3-0-6);* For course description, see Biochemistry & Molecular Biophysics

BMB/Bi/Ch 174. Macromolecular Machines of the Central Dogma. *6 units (3-0-3);* For course description, see Biochemistry & Molecular Biophysics

CNS/Bi/Psy/NB 176. Cognition. *9 units (4-0-5);* For course description, see Computation & Neural Systems

Bi/BE 177. Principles of Modern Microscopy. *9 units (3-0-6); second term.* Lectures and discussions on the underlying principles behind digital, video, differential interference contrast, phase contrast, confocal, and two-photon microscopy. The course will begin with basic geometric optics and characteristics of lenses and microscopes. Specific attention will be given to how different imaging elements such as filters, detectors, and objective lenses contribute to the final image. Course work will include critical evaluation of published images and design strategies for simple optical systems and the analysis and presentation of two- and three-dimensional images. The role of light microscopy in the history of science will be an underlying theme. No prior knowledge of microscopy will be assumed. Given in alternate years; not offered 2025-26. Instructor: Collazo.

Ge/ESE/Bi 178. Microbial Ecology. *9 units (3-2-4);* For course description, see Geology

Bi 180. Plant and Soil Science. *9 units (2-2-5); first term.* Plants comprise most of the mass of living things on land, serve as the ultimate source of almost all human food and energy, and are a dominating force in the carbon and oxygen cycles. This lecture, reading and lab course will introduce topics in plant systematics, evolution, genetics, genomics, development, and ecology, with emphasis on plant interactions with soil and the bacteria, fungi, and animals that inhabit it. There are two hours of lecture per week and 90 minutes of laboratory sessions (in two sections), in which plants and soil samples are collected on campus and brought to the lab for analysis. Enrollment is limited to 40 students. Students from all options are welcome. Instructor: Meyerowitz.

Bi/BE/CS 183. Introduction to Computational Biology and Bioinformatics. *9 units (3-0-6); third term. Prerequisites: Bi 8, CS 2, Ma 3; or BE/Bi 103 a; or instructor's permission.* Biology is becoming an increasingly data-intensive science. Many of the data challenges in the biological sciences are distinct from other scientific disciplines because of the complexity involved. This course will introduce key computational, probabilistic, and statistical methods that are common in computational biology and bioinformatics. We will integrate these theoretical aspects to discuss solutions to common challenges that reoccur throughout bioinformatics including algorithms and heuristics for tackling DNA sequence alignments, phylogenetic reconstructions, evolutionary analysis, and population and human genetics. We will discuss these topics in conjunction with common applications including the analysis of high throughput DNA sequencing data sets and analysis of gene expression from RNA-Seq data sets. Instructor: Pachter.

ESE/Ge/Bi/ChE 184. Computational Tools for Decoding Microbial Ecosystems. *9 units (3-0-6);* For course description, see Environmental Science & Engineering

CNS/Bi/EE/CS/NB 186. Vision: From Computational Theory to Neuronal Mechanisms. *12 units (4-4-4);* For course description, see Computation & Neural Systems

CNS/Bi/Ph/CS/NB 187. Neural Computation. *9 units (3-0-6);* For course description, see Computation & Neural Systems

Bi 188. Human Genetics and Genomics. *6 units (2-0-4); third term. Prerequisites: Bi 122; or graduate standing and instructor's permission.* Introduction to the genetics of humans. Subjects covered include human genome structure, genetic diseases and predispositions, the human genome project, forensic use of human genetic markers, human variability, and human evolution. Given in alternate years; not offered 2025-26. Instructor: Staff.

Bi/BMB 189. The Cell Cycle and Genomic Stability. *6 units (2-0-4); third term. Prerequisites: Bi 8 and Bi 9.* The course covers the mechanisms by which eukaryotic cells control their duplication in a properly regulated manner. A large emphasis will be placed on the controls that cells employ to replicate and segregate their chromosomes with the necessary precision. In addition, the course will examine the mechanisms by which cells detect and rectify damaged DNA throughout the cell cycle. These various processes, collectively known as checkpoint-regulatory mechanisms, lie at the heart of how organisms maintain genomic integrity throughout their lifetimes. These pathways are essential for the prevention of cancer, birth defects, and other maladies. As part of the course, students will give presentations on key publications in the field, including both classic papers and newer papers that employ cutting-edge technologies. Instructor: Dunphy.

Bi 190. Systems Genetics. *6 units (2-0-4); third term. Prerequisites: Bi 122.* Lectures covering how genetic and genomic analyses are used to understand biological systems. Emphasis is on genetic and genome-scale approaches used in model organisms such as yeast, flies, worms, and mice to elucidate the function of genes, genetic pathways and genetic networks. Given in alternate years; offered 2025-26. Instructors: Nolan, Sternberg.

BE/CS/CNS/Bi 191 ab. Biomolecular Computation. *9 units; part a (3-0-6) and part b (2-4-3);* For course description, see Bioengineering

Bi 192. Introduction to Systems Biology. *6 units (2-0-4); first term. Prerequisites: Ma 1 abc, and either Bi 8, CS 1, or ACM 95 or instructor's permission.* The course will explore what it means to analyze biology from a systems-level point of view. Given what biological systems must do and the constraints they face, what general properties must biological systems have? Students will explore design principles in biology, including plasticity, exploratory behavior, weak-linkage, constrains that deconstrain, robustness, optimality, and evolvability. The class will read the equivalent of 2-3 scientific papers every week. The format will be a seminar with active discussion from all students. Students from multiple backgrounds are welcome: non-biology or biology students interested in learning systems-level questions in biology. Limited enrollment. Not offered 2025-26. Instructor: Goentoro.

Bi/CNS/NB 195. Mathematics in Biology. *9 units (3-0-6); first term. Prerequisites: calculus.* This course develops the mathematical methods needed for a quantitative understanding of biological phenomena, including data analysis, formulation of simple models, and the framing of quantitative questions. Topics include: probability and stochastic processes, linear algebra and transforms, dynamical systems, scientific programming. Instructor: Thomson.

BE/Bi/CNS/NB 197. Mentoring and Outreach. *Units to be arranged, up to 12 units per year;* For course description, see Bioengineering

BE/Bi/NB 203. Introduction to Programming for the Biological Sciences Bootcamp. *6 units;* For course description, see Bioengineering

BE/Bi 205. Deep Learning for Biological Data. *9 units (3-0-6);* For course description, see Bioengineering

Bi 214. Stem Cells and Hematopoiesis. *9 units (3-0-6); second term. Prerequisites: Graduate standing, or at least one of Bi 114, Bi 117, Bi/Be 182, plus molecular biology.* An advanced course with classes based on active discussion, lectures, and seminar presentations. Development from embryos and development from stem cells are distinct paradigms for understanding and manipulating the emergence of ordered biological complexity from simplicity. This course focuses on the distinguishing features of stem-cell based systems, ranging from the natural physiological stem cells that are responsible for life-long hematopoiesis

in vertebrates (hematopoietic stem cells) to the artificial stem cells, ES and iPS cells, that have now been created for experimental manipulation. Key questions will be how the stem cells encode multipotency, how they can enter long-term self-renewal by separating themselves from the developmental clock that controls development of the rest of the organism, and how the self-renewal programs of different stem cell types can be dismantled again to allow differentiation. Does "stem-ness" have common elements in different systems? The course will also cover the lineage relationships among diverse differentiated cell types emerging from common stem cells, the role of cytokines and cytokine receptors in shaping differentiation output, apoptosis and lineage-specific proliferation, and how differentiation works at the level of gene regulation and regulatory networks. Given in alternate years; not offered 2025-26. Instructor: Rothenberg.

NB/Bi/CNS 216. Behavior of Mammals. *6 units (2-0-4);* For course description, see Neurobiology

NB/Bi/CNS 220. Genetic Dissection of Neural Circuit Function. *6 units (2-0-4);* For course description, see Neurobiology

Bi/BE/BMB 222. The Structure of the Cytosol. *6 units (2-0-4); third term. Prerequisites: Bi 9, Ch/Bi 110-111 or graduate standing in a biological discipline.* The cytosol, and fluid spaces within the nucleus, were once envisioned as a concentrated soup of proteins, RNA, and small molecules, all diffusing, mixing freely, and interacting randomly. We now know that proteins in the cytosol frequently undergo only restricted diffusion and become concentrated in specialized portions of the cytosol to carry out particular cellular functions. This course consists of lectures, reading, student presentations, and discussion about newly recognized biochemical mechanisms that confer local structure and reaction specificity within the cytosol, including protein scaffolds and "liquid-liquid phase separations" that form "membraneless compartments". Instructor: Kennedy.

Bi/BE 227. Methods in Modern Microscopy. *12 units (2-6-4); second term. Prerequisites: Bi/BE 177 or a course in microscopy.* Discussion and laboratory-based course covering the practical use of the confocal microscope, with special attention to the dynamic analysis of living cells and embryos. Course topics include: basic optics, microscope design, Kohler illumination, confocal microscopy, light sheet microscopy, deeper imaging into tissues using two photon laser scanning microscopy with non-descanned detectors, comparing fluorescence correlation spectroscopy (FCS) to fluorescence recovery after photobleaching (FRAP) and three-dimensional reconstruction of cells and tissues. Students will construct a light sheet microscope based on the openSPIM design, and perform time-lapse confocal analysis of living cells and embryos. Enrollment is limited. Offered 2025-26. . Instructor: Collazo.

Bi/CNS/BE/NB 230. Optogenetic and CLARITY Methods in Experimental Neuroscience. *9 units (3-2-4); third term. Prerequisites:*

Graduate standing or NB/Bi/CNS 150 or equivalent or instructor's permission. The class covers the theoretical and practical aspects of using (1) optogenetic sensors and actuators to visualize and modulate the activity of neuronal ensembles; and (2) CLARITY approaches for anatomical mapping and phenotyping using tissue-hydrogel hybrids. The class offers weekly hands-on LAB exposure for opsin viral production and delivery to neurons, recording of light-modulated activity, and tissue clearing, imaging, and 3D reconstruction of fluorescent samples. Lecture topics include: opsin design (including natural and artificial sources), delivery (genetic targeting, viral transduction), light activation requirements (power requirements, wavelength, fiberoptics), compatible readout modalities (electrophysiology, imaging); design and use of methods for tissue clearing (tissue stabilization by polymers/hydrogels and selective extractions, such as of lipids for increased tissue transparency and macromolecule access). Class will discuss applications of these methods to neuronal circuits (case studies based on recent literature). Given in alternate years; not offered 2025-26. Instructor: Gradinaru.

Bi/BE/CNS/NB 241. Spatial Genomics. *9 units (1-8-0); third term. Prerequisites: Instructor's permission.* Maximum enrollment: 12. Applications of spatial genomics technology to various biological samples. Projects will be selected to represent problems in neurobiology, developmental biology and translational medicine. Emphasis will be placed on generating experimental data and analysis of data with machine learning algorithms for segmentation and clustering cells with single cell genomics tools, and preparation for publication. Instructor: Cai.

Ge/Bi 244. Paleobiology Seminar. *6 units (3-0-3);* For course description, see Geology

Ge/Bi/ESE 246. Molecular Geobiology Seminar. *6 units (2-0-4);* For course description, see Geology

CNS/Bi/NB 247. Cerebral Cortex. *6 units (2-0-4);* For course description, see Computation & Neural Systems

Ge/ESE/Bi 248. Environmental Justice. *6 units (2-0-4);* For course description, see Geology

Ge/Bi/ESE/CE 249. Stable Isotopes: Ecological and Environmental Applications. *9 units (3-3-3);* For course description, see Geology

Bi 250 a. Topics in Molecular and Cellular Biology. *9 units (3-0-6); first term. Prerequisites: graduate standing.* This course will cover 4-5 major discoveries in modern molecular biology, with the goal of analyzing the methods, scientific concepts and logic, research strategies, and scientists that underlie these advances. Students will learn to critique papers in a wide range of fields, including molecular biology, developmental biology, genetics, and neuroscience. As an opportunity to

hone their communication and teaching skills, students will develop and implement a hands-on demonstration of a molecular biology concept to local elementary students in the PUSD school system. Graded pass/fail. Instructor: Voorhees.

Bi 250 b. Topics in Systems Biology. *9 units (3-0-6); third term. Prerequisites: Bi 1, Bi 8, or equivalent; Ma 2, Bi/CNS/NB 195, or equivalent; or instructor's permission.* Quantitative studies of cellular and developmental systems in biology, including the architecture of specific circuits controlling microbial behaviors and multicellular development in model organisms. Specific topics include chemotaxis, multistability and differentiation, biological oscillations, stochastic effects in circuit operation, as well as higher-level circuit properties, such as robustness. The course will also consider the organization of transcriptional and protein-protein interaction networks at the genomic scale. Topics are approached from experimental, theoretical, and computational perspectives. Instructors: Elowitz, Bois.

NB/Bi/CNS 250 c. Topics in Systems Neuroscience. *9 units (3-0-6);* For course description, see Neurobiology

Bi 250 d. Topics in Developmental, Stem Cell and Evolutionary Biology. *9 units (3-0-6); second term. Prerequisites: graduate standing.* Lectures and literature-based discussions on the principles and experimental frontiers of embryonic axis organization, pattern formation, genomic mechanisms of cell type specification, stem cell biology, and evolutionary change. Instructors: Bronner, Rothenberg, Zernicka-Goetz.

Bi/BMB 251 abc. Current Research in Biology and Biological Engineering. *1 unit; first, second. Prerequisites: graduate standing.* Presentations and discussion of research in biology and biological engineering. Presented by second and fourth year graduate students, postdocs, and faculty. Instructors: Hay, Sternberg.

Bi 252. Responsible Conduct of Research. *4 units (2-0-2); first term.* This lecture and discussion course covers relevant aspects of the responsible conduct of biomedical and biological research. Topics include guidelines and regulations, ethical and moral issues, research misconduct, data management and analysis, research with animal or human subjects, publication, conflicts of interest, mentoring, and professional advancement. Undergraduate students with junior and senior standing may enroll. Graded pass/fail. Instructors: Meyerowitz, Sternberg.

Ch/Bi 253. Advanced Topics in Biochemistry. *6 units (2-0-4);* For course description, see Chemistry

Psy/Bi/CNS 255. Topics in Emotion and Social Cognition. *9 units (3-0-6);* For course description, see Psychology

CNS/Bi/NB 256. Brain-machine interfaces. *6 units (2-0-4);* For course description, see Computation & Neural Systems

Bi 265. Biological Research: Fellowship Application and Science Communication. *6 units (2-3-1); summer term.* This course focuses on clear communication of scientific research in grant writing, networking, and research presentation. Practice is obtained through the following facilitated activities: 1) drafting the required statements for an NSF-GRFP proposal, 2) developing a networking pitch for use with non-scientists and scientists, and 3) presenting research to a scientific audience. First and second year graduate students, senior undergrads, and rising senior undergrads can enroll. Not offered 2025-26. Instructor: Staff.

Bi 270 abc. Special Topics in Biology. *Units to be arranged each term; first, second, third terms.* Students may register with permission of the responsible faculty member.

CNS/Bi 286 abc. Special Topics in Computation and Neural Systems. *Units to be arranged;* For course description, see Computation & Neural Systems

Bi 299. Graduate Research. *Units to be arranged; first, second, third terms.* Students may register for research units after consultation with their adviser.

BUSINESS ECONOMICS & MANAGEMENT

BEM 97. Undergraduate Research. *Units to be arranged; any term. Prerequisites: advanced BEM and instructor's permission.* This course offers advanced undergraduates the opportunity to pursue research on a business problem individually or in a small group. Graded pass/fail. Instructor: Staff.

BEM 101. Selected Topics in Business Economics and Management. *Units to be determined by arrangement with the instructor; offered by announcement.* Topics determined by instructor. Instructors: Staff, visiting lecturers.

BEM 102. Introduction to Accounting. *9 units (3-0-6); first term.* This course combines accounting and finance in a dynamic, user-oriented approach. The goal is to enable students to understand what financial statements are (sources of information about a company), what they are not (facts devoid of interpretation or management influence), and how to critically understand and analyze them. The course will utilize actual SEC filings for several companies, across a variety of industries, through which the students will be exposed to important accounting concepts. Not offered 2025-26.

BEM 103. Introduction to Finance. *9 units (3-0-6); second term. Prerequisites: Ec 11 required; Ma 1 abc recommended (to be familiar with calculus and linear algebra).* Finance, or financial economics, covers two main areas: asset pricing and corporate finance. For asset pricing, a field that studies how investors value securities and make investment decisions, we will discuss topics like prices, risk, and return, portfolio choice, CAPM, market efficiency and bubbles, interest rates and bonds, and futures and options. For corporate finance, a field that studies how firms make financing decisions, we will discuss topics like security issuance, capital structure, and firm investment decisions (the net present value approach, and mergers and acquisitions). In addition, if time permits, we will cover some topics in behavioral finance and household finance such as limits to arbitrage and investor behavior. Instructor: Rosenthal.

BEM 104. Investments. *9 units (3-0-6); first term. Prerequisites: Ec 11, BEM 103, some familiarity with statistics.* Examines the theory of financial decision making and statistical techniques useful in analyzing financial data. Topics include portfolio selection, equilibrium security pricing, empirical analysis of equity securities, fixed-income markets, market efficiency, and risk management. Instructor: Cvitanic.

BEM 105. Options. *9 units (3-0-6); first term. Prerequisites: One of the following: Ec 122, Ge/ESE 118, Ma 1/103, MA 112 a, MA 112 b, or instructor's permission; BEM 103 strongly recommended; some familiarity with differential equations is helpful.* An introduction to option pricing theory and risk management in the discrete-time, bi-nomial tree model, and the continuous time Black-Scholes-Merton framework. Both the partial differential equations approach and the martingale approach (risk-neutral pricing by expected values) will be developed. The course will cover the basics of Stochastic, Ito Calculus. Since 2015, the course is offered in the flipped format: the students are required to watch lectures online, while problem solving and case and paper presentations are done in class. Instructor: Cvitanic.

BEM 106. Data Science in Economics. *9 units (3-0-6); third term.* This course revolves around qualitative topics and quantitative methods in data science for finance and economics. We discuss linear models and inference, sources of bias, databases and data validation, scraping, clustering, and text analysis. A special emphasis is placed on developing a robust understanding of the strengths and weaknesses of social science research methods. The class also introduces students to the Python programming language and its ecosystem of packages. Instructor: Janas.

BEM 107. Corporate Finance. *9 units (3-0-6); third term. Prerequisites: BEM 103.* The main objective of the course is to develop insight into the process by which firms can create value for their shareholders. We will study major corporate decisions from the perspective of the firm with an emphasis on the interaction of the firm with financial markets: quantitative project evaluation for investment, choice between borrowing

and issuing stock, dividend policy, organizational form (for example, mergers and acquisitions). Theory, empirical evidence, and case analysis all play significant roles in the course. Topics include discounted cash flow models, risk and return, capital asset pricing model, capital market efficiency, capital structure and the cost of capital and dividend policy. Not offered 2025-26.

BEM 108. Mathematical Models in Fintech. *9 units (3-0-6); third term. Prerequisites: Some knowledge of game theory and optimization is helpful, BEM 103 Introduction to Finance is recommended, and a calculus-based course in probability is required.* In this course we will go over recent works on topics broadly contained in the newly emerging field of Fintech. In particular, the topics include mathematical modeling of strategic actions of agents interacting via a blockchain technology, via crowdfunding platforms, and via online investment platforms ("robo-advisors"). Not offered 2025-26.

BEM 109. Understanding China through Finance. *9 units (3-0-6); first term. Prerequisites: BEM 103.* In this course we will develop a deep understanding of the institutional foundations of Chinese finance, and we will use this framework to study the strengths and weaknesses of the Chinese economic system through the lens of finance. We will start from a historical overview of Chinese finance and will study the institutions that drive financial market development. Next, we will focus on the unique economic features of the three main channels of Chinese finance: capital markets (including the stock and bond markets), bank- and fund-based intermediation (including the banking sector, shadow-banking, and private equity, and venture capital), and informal finance. Finally, we will study the opportunities and challenges posed by Chinese-style finance for the future development of the global financial system. Instructor: Sinclair.

BEM 110. Venture Capital. *9 units (3-0-6); second term. Prerequisites: BEM 102, 103.* An introduction to the theory and practice of venture capital financing of start-ups. This course covers the underlying economic principles and theoretical models relevant to the venture investment process, as well as the standard practices used by industry and detailed examples. Topics include: The history of VC; VC stages of financing; financial returns to private equity; LBOs and MBOs; people versus ideas; biotech; IPOs; and CEO transitions. Not offered 2025-26.

BEM 111. Quantitative Risk and Portfolio Management. *9 units (3-0-6); second term. Prerequisites: GE/ACM 118, BEM 105, or Ma 112.* Investors demand reward for taking risk. Concepts of Knightian risk and uncertainty; risk preference (risk-neutral Q vs. real-world P probability measures); coherent risk; and commonly used metrics for risk are explored. The integration of risk and reward in classical efficient portfolio construction is described, along with the drawbacks of this approach in practice and methods for addressing these drawbacks. The leptokurtic (fat-tailed) nature of financial data and approaches to modeling financial surprises are covered, leading to inherently leptokurtic techniques for

estimating volatility and correlation. Scenario analysis, and regime-switching methods are shown to provide ways of dealing with risk in extreme environments. The special nature of modeling long/short portfolios (hedge funds) is explored. The text for the class is a Jupyter Notebook with Python code segments. Instructor: Winston.

BEM 112. International Financial Markets. *9 units (3-0-6); second term. Prerequisites: BEM 103 or instructor permission.* The course offers an introduction to international financial markets, their comparative behavior, and their inter-relations. The principal focus will be on assets traded in liquid markets: currencies, equities, bonds, swaps, and other derivatives. Attention will be devoted to (1) institutional arrangements, taxation, and regulation, (2) international arbitrage and parity conditions, (3) valuation, (4) international diversification and portfolio management, (5) derivative instruments, (6) hedging, (7) dynamic investment strategies, (8) other topics of particular current relevance and importance. Not offered 2025-26.

BEM 113. Law and Finance for Start-Ups. *9 units (3-0-6); third term. Prerequisites: Ec 11, E 102, or equivalent.* This course combines elements of business, economics, engineering, financial statement analysis, strategy, and law to provide students interested in entrepreneurship with a practical understanding of the mechanics of growing a 'post-idea' company. The class will explain how prospective investor's view entrepreneurs and their ideas, teach students about types of capital, sources of capital, and term sheets, and generally delve into the timing and financial alternatives and trade-offs facing entrepreneurs seeking capital in order to launch or grow a company. As such, this class is a complement to BEM 110 (Venture Capital) and E 102 (Scientific and Technology Entrepreneurship). Not offered 2025-26.

BEM 114. Hedge Funds. *9 units (3-0-6); third term. Prerequisites: BEM 103.* This course is an in-depth study of the hedge fund industry. We will study hedge fund trading strategies, the business model of hedge funds, hedge fund investors, as well as the institutional and regulatory framework in which hedge funds operate. The course will evaluate and analyze popular hedge fund trading strategies, including equity strategies (activist, market-neutral, long/short, event-driven, etc.), arbitrage strategies (derivatives, convertible, fixed-income, currency and global macro, etc.), and fund of hedge funds. The course will also analyze the hedge fund business model, including: performance evaluation and risk management; fund compensation and contractual features; transaction costs and market impact; as well as fund raising and marketing. In addition, the course will study the institutional relationships hedge funds have with service providers (prime brokers, custodian banks, etc.) and with regulators. We will also discuss public policy implications and the value of hedge funds in society. This course is designed to provide students with the skills necessary to evaluate hedge fund strategies, and to develop, manage, and successfully grow a hedge fund business. Instructor: Sinclair.

BEM 115. Business Law. *9 units (3-0-6); second term. Prerequisites: Ec 11 or equivalent.* This course will serve as an introduction to the American legal system emphasizing concepts which students are likely to encounter in their professional lives such as Constitutional law (federalism; statesâ rights; structure of court systems), dispute resolution (litigation; mediation; arbitration), contracts (elements; defenses to formation; remedies), employment law, business associations (partnerships; corporations; LLCs), securities regulation, and intellectual property (patents; trademarks; trade secrets; copyrights). By learning to identify issues which would alert one to the need for a lawyer, the class will sensitize students to key legal issues they may encounter in the normal course of business. Textbook reading and lectures will be supplemented by practicing lawyers expert in their field of business law as guest speakers. Instructor: McAniff.

BEM 117. Behavioral Finance. *9 units (3-0-6); third term. Prerequisites: Students are recommended (but not required) to take BEM 103 to become familiar with some basic concepts in finance.* Much of modern financial economics works with models in which agents are fully rational, in that they maximize expected utility and use Bayes' law to update their beliefs. Behavioral finance is a large and active field that develops and studies models in which some agents are less than fully rational. Such models have two building blocks: limits to arbitrage, which makes it difficult for rational traders to undo the dislocations caused by less rational traders; and psychology, which provides guidance for the kinds of deviations from full rationality we might expect to see. We discuss these two topics and consider a number of applications: asset pricing; individual trading behavior; the origin of bubbles; and financial crises. Not offered 2025-26.

BEM/Ec/ESE 119. Environmental Economics. *9 units (3-0-6); third term. Prerequisites: Ec 11 or equivalent.* This course provides a survey from the perspective of economics of public policy issues regarding the management of natural resources and the protection of environmental quality. The course covers both conceptual topics and recent and current applications. Included are principles of environmental and resource economics, management of nonrenewable and renewable resources, and environmental policy with the focus on air pollution problems, both local problems (smog) and global problems (climate change). Instructor: Druckenmiller.

BEM/Ec 120. Introduction to Sports Science. *9 units (3-0-6); third term.* The use of large data sets and innovative statistical methods has revolutionized professional and intercollegiate sports. This course introduces students to the academic and professional world of contemporary sports science. The course will meet biweekly with instructor lectures on sports science and with guest speakers from collegiate and professional sports. Students will be introduced to the primary data sources for sports science, to methods used to collect sports performance and outcomes data, and to the statistical tools used for sports analytics (for example, logistic regression, regression trees

and random forest, network models, time series, and natural language processing). Students will be responsible for weekly writing or homework assignments based on readings and speaker presentations, as well as a quarter-long sports analytics research project. Students should have some background in econometrics, statistics and probability, data science, or machine learning. Not offered 2025-26.

BEM/Ec 131. International Trade and Finance. *9 units (3-0-6); fall term. Prerequisites: BEM 103 and Ec 11.* In this course, we will study the global economy and how it is shaped by the interaction between market forces and government policy. We will build a foundational understanding of the economics of international trade and finance and examine the incentives that drive the behavior of firms, investors, and governments. Topics will include comparative advantage, factor endowments, and the gains from trade; tariffs, industrial policy, and regional trade agreements; exchange rate regimes, interest rate parity, sovereign debt, and financial crises. Throughout the course, we will frame our analysis within a broader institutional and historical context, examining how global economic systems have been organized through periods of colonialism, globalization, and geoeconomic rivalry. Instructor: Sinclair.

CHEMICAL ENGINEERING

Ch/ChE 9. Chemical Synthesis and Characterization for Chemical Engineering. *9 units (1-6-2);* For course description, see Chemistry

ChE 10. Introduction to Chemical Engineering. *1 unit (1-0-0); first term.* This course will introduce the Chemical Engineering discipline, career options and research opportunities through lectures and panel discussions by faculty and alumni. Graded pass/fail. Instructor: Dingilian.

ChE 15. Introduction to Chemical Engineering Computation. *9 units (1-3-5); second term. Prerequisites: CS 1 or instructor's permission.* Introduction to computational methods and tools with emphasis on their application to chemical engineering. Basic knowledge of Python is assumed. The course will focus on writing Python code to solve and present results of scientific and engineering computations and data analysis, and the use of methods in Python libraries, including NumPy, SciPy, and MatPlotLib . Students are expected to attend a lecture/discussion session and two computational laboratories weekly. Instructor: Flagan.

ChE 62. Material Balances and Separation Processes. *9 units (3-0-6); third term. Prerequisites: ChE 15 and Ma 2.* Fundamentals of chemical engineering material balances and separation process. First half: analysis of single and multi-unit processes with reactive and non-reactive components. Second half: liquid-liquid extraction, flash and column distillation, membrane separation, and additional separation

process of student choice. Instructor: Dingilian.

ChE 63 ab. Chemical Engineering Thermodynamics. *9 units (3-0-6); first, second terms. Prerequisites: Sophomore standing required.* A comprehensive treatment of classical thermodynamics with engineering and chemical applications. First and second laws. Applications to closed and open systems. Equations of state. Thermochemical calculations. Properties of real fluids. Power generation and refrigeration cycles. Multicomponent systems, excess properties, fugacities, activity coefficients, and models of nonideal solutions. Chemical potential. Phase and chemical reaction equilibria. Instructors: Dingilian (a), Ismagilov (b).

ChE 70. Special Topics in Chemical Engineering. *Units by arrangement; terms to be arranged. Prerequisites: instructor's permission.* Special problems or courses arranged to meet the emerging needs of undergraduate students. Topics have included AIChE's annual Chem-E-Car Competition. May be repeated for credit, as content may vary. Grading scheme at instructor's discretion.

ChE 80. Undergraduate Research. *Units by arrangement, instructor's permission required;* Research in chemical engineering offered as an elective in any term. Graded pass/fail.

ChE 90 abc. Undergraduate Thesis. *9 units (0-4-5); terms to be arranged.* A research project carried out under the mentorship of an approved faculty member. Before the beginning of the first term of the thesis, students must submit a proposal - with project details and significant design component clearly defined - for review and approval by the thesis mentor and chemical engineering Undergrad Option Rep. In addition, students must submit the following to the thesis mentor and chemical engineering senior thesis coordinator: a midterm progress report in each term; end-of-term progress reports at the end of the first two terms; and a thesis draft in the third term. A grade will not be assigned prior to completion of the thesis, which normally takes three terms. A P grade will be given for the first two terms and then changed to the appropriate letter grade at the end of the course.

Ch/ChE 91. Scientific Writing. *3 units (2-0-1);* For course description, see Chemistry

ChE 101. Chemical Reaction Engineering. *9 units (3-0-6); second term. Prerequisites: ChE 62, ChE 63 ab, ChE 103 a or instructor's permission.* Elements of chemical kinetics and chemically reacting systems. Chemical reactor analysis. Homogeneous and heterogeneous catalysis. Biological and environmental reaction engineering. Enzyme kinetics. Lectures include case studies from real world applications of various chemical engineering subfields. Problem sets contain computational approaches to chemical kinetics and reactor design. Instructor: Demirer.

ChE 103 abc. Transport Phenomena. *9 units (3-0-6); first, second, third terms. Prerequisites: ACM 95/100 ab or concurrent registration; ChE 101 required for ChE 103 c or instructor's permission.* A rigorous development of the basic differential equations of conservation of momentum, energy, and mass in fluid systems. Solution of problems involving fluid flow, heat transfer, and mass transfer. Instructors: Fong (a), Shapiro (b), Manthiram (c).

ChE 105. Dynamics and Control of Chemical Systems. *9 units (3-0-6); third term. Prerequisites: ACM 95 ab or concurrent registration, or instructor's permission.* An introduction to analysis and design of feedback control systems in the time and frequency domain, with an emphasis on state space methods, robustness, and design tradeoffs. Linear input/output systems, including input/output response via convolution, reachability, and observability. State feedback methods, including eigenvalue placement, linear quadratic regulators, and model predictive control. Output feedback including estimators and two-degree of freedom design. Input/output modeling via transfer functions and frequency domain analysis of performance and robustness, including the use of Bode and Nyquist plots. Robustness, tradeoffs and fundamental limits, including the effects of external disturbances and unmodeled dynamics, sensitivity functions, and the Bode integral formula. Instructor: Vicic.

ChE/Ch/Bi/SEC 107. Social Media for Scientists. *9 units (3-0-6); second term.* An introduction to the use of social media for scientific communication. Social media platforms are discussed in the context of their use to professionally engage scientific communities and general audiences. Topics will include ethics, privacy, reputation management, ownership and the law, and will focus on the use and impact of social media for personal and professional career development. Lectures will include presentations by invited experts in various specialties, a number of whom will have worldwide recognition. Not offered 2025-26.

ChE/ESE/ME/MS 111. Sustainable Engineering. *9 units (3-0-6); second term. Prerequisites: (ChE 62 and ChE 63 ab) or (ME 11 abc) or (Ph 2 c and MS 115) or Instructor's permission.* Examines the Earth's resources including fresh water, nitrogen, carbon and other biogeochemical cycles that impose planetary constraints on engineering; systems approaches to sustainable development goals; fossil fuel formation, chemical composition, production and use; engineering challenges and opportunities in decarbonizing energy, transportation and industry; global flows of critical elements used in zero-carbon energy systems; food-water-energy nexus and effects of human on air, water and soil. Instructor: Kornfield.

ChE/BE/MedE 112. Enhancing Technical Creativity with AI Tools in the Context of Microfluidics for Global Health. *9 units (3-0-6); second term.* The goal of the course is to teach students technical creativity (ideas that solve problems) and how to use artificial intelligence tools developed in the course to enhance their creativity further. Because

technical creativity needs a specific context, we selected the context of microfluidic technologies and global health challenges. This course combines three parts. First, students will dive deeply into human and AI augmented technical creativity. Second, students will dive into the physics, kinetics, and transport fundamentals that underpin microfluidic technologies and explore examples of translation of technologies into practice. Finally, students will collaborate in teams to apply their creativity to global health challenges. AI tools will be introduced to aid students in generating and evaluating ideas. Students will be encouraged and helped, but not required, to develop their inventions further by working with OTTCP and entrepreneurial resources on campus. The course benefits from the enrollment of students with diverse backgrounds and interests. Students are encouraged to contact the instructor to discuss enrollment. Instructor: Ismagilov.

ChE/Ch/MS 113. Squishy Engineering: Using Soft Materials to Solve Hard Problems. *9 units (3-0-6); third term. Prerequisites: ChE 63ab or equivalent, ChE 103ab or equivalent, and ChE 101 or equivalent; or instructor's permission.* The milk we drink in the morning (a colloidal dispersion), the gel we put into our hair (a polymer network), and the plaque that we try to scrub off our teeth (a biofilm)are all familiar examples of soft materials. Such materials also hold great promise in helping to solve engineering challenges like drug delivery, water remediation, and sustainable agriculture, as well as the development of new coatings, displays, formulations, food, and biomaterials. This class will cover fundamental aspects of the science of soft materials, presented within the context of these challenges. We will also have guest speakers describe new applications of soft materials. Instructor: Datta.

ChE 114. Solid State NMR Spectroscopy For Materials Chemistry. *9 units (3-3-3); second term. Prerequisites: Ch 21 abc or instructor's permission.* This course covers the principles and applications of solid-state NMR spectroscopy, with a focus on structural and dynamic characterization of organic and inorganic solids. Key applications include the analysis of heterogeneous catalysts, battery materials, and other energy storage systems. Topics include fundamental and advanced solid-state NMR techniques such as magic angle spinning (MAS), cross-polarization (CP), NMR of quadrupolar nuclei, multiple-pulse sequences, multi-dimensional experiments, sensitivity enhancement methods, and NMR methods for probing molecular dynamics. Recent advances in the field such as the integration of machine learning and artificial intelligence (AI) for automated spectral analysis, structural prediction, and data-driven materials discovery will also be briefly reviewed. Hands-on laboratory sessions using solid-state NMR spectrometers at the Caltech Solid State NMR Facility provide practical experience. Instructor: Hwang.

ChE 115. Electronic Materials Processing. *9 units (3-0-6); third term. Prerequisites: ChE 63 ab, ChE 103 abc, ChE 101, or instructor's permission.* A broad introduction into the gas-phase techniques used to process semiconductor surfaces, from etching to deposition and surface

modification. Topics include: Kinetic theory of gases. Surface chemistry and gas-surface interaction dynamics. Physical and chemical vapor deposition of amorphous, polycrystalline and epitaxial layers. Introduction into processing plasmas and their unique ability to drive non-thermal chemistry on surfaces for precisely etch patterns and deposit layers in confined spaces. Role of ions and determination of key parameters that control the ion energy and flux to surfaces. Instructor: Giapis.

ChE 118. Introduction to the Design of Chemical Systems. *9 units (3-0-6); second term. Prerequisites: ChE 126, or instructor's permission.* Student groups complete high-level design of a chemical process or product, while learning about and using the engineering design cycle, methods of creativity, technology evaluation, and entrepreneurship. Each team generates, filters, and refines project concepts; identifies stakeholders, needs, and requirements; ideates and evaluates technologies, selecting suitable options based on readiness, benefits, and strategy; develops a project budget and schedule for a proof of concept; and writes a proposal. Each project must meet requirements for societal impact, budget, duration, person hours, environmental impact, safety, and ethics. Instructor: Vicic.

ChE 120. Optimal Design of Chemical Systems. *9 units (0-6-3); third term. Prerequisites: ChE 126, or instructor's permission.* After selecting a project from a collection of proposals, student groups design, build, and test a proof of concept for the proposed chemical process or product, subject to schedule, financial, and other constraints. Students are encouraged and helped, but not required, to collaborate with on-campus subject-matter experts, laboratories/centers, and OTT/entrepreneurial resources. Instructor: Vicic.

ChE 126. Chemical Engineering Laboratory. *9 units (1-6-2); first term. Prerequisites: ChE 63 ab, ChE 101, ChE 103 abc, ChE 105, or instructor's permission.* In this capstone course, students design, build, and test a proof of concept for a chemical process or product, subject to constraints related to finances, schedule, environmental impact, safety, and ethics. Students learn about and use methods of creativity, the engineering design cycle, and rapid prototyping. Instructor: Vicic.

ChE 128. Chemical Engineering Design Laboratory. *9 units (1-6-2); second term. Prerequisites: ChE 63 ab, ChE 101, ChE 103 abc, ChE 105 or instructor's permission.* Short-term, open-ended research projects targeting chemical processes and materials. Each student is required to design, construct, and troubleshoot their own process, then use chemical engineering principles to experimentally evaluate and optimize process metrics or material attributes. Where possible, cost analysis is performed. Not offered 2025-26. . Instructors: Giapis, Vicic.

ChE/Ch/BE 130. Biomolecular Engineering Laboratory. *9 units (0-6-3); third term. Prerequisites: BE/ChE 163 or instructor's permission.* Design, construction, and characterization of engineered biological systems.

Students propose and execute research projects in biomolecular engineering, synthetic biology, and genetic engineering fields. Projects will cover a broad range of molecular and cell biology, and genetics and genomics lab techniques. Instructor: Demirer.

ChE/Ch 137. Data Science for Chemical Systems. *9 units (2-1-6); second term. Prerequisites: Ch 41b.* Through lectures, in-class activities, and problem sets, students learn and use methods in data science to execute a project focused on a Quantitative Structure Property Relationship (QSPR). Students complete a typical research-based data science pipeline, including project definition, metric evaluation, data collection, data cleaning, exploratory data analysis, model selection, visualization, and reporting. During data cleaning and exploratory data analysis, students learn key concepts about univariate and multivariate statistics. Throughout the project, students learn about bias and fairness, the reproducibility crisis, statistical paradoxes, and more. Python is the programming language of instruction. Instructor: Vicic.

ChE/Ch 139. Challenges in Data Science for Chemical Systems. *9 units (1-0-8); third term. Prerequisites: ChE/Ch 137.* Student groups complete a one-term, data-science project that addresses an instructor-approved chemical engineering challenge. The project may be an original research idea; related to work by a research group at the Institute; an entry in a relevant national/regional contest; a response to an industry relationship; or other meaningful opportunity. There is no lecture, but students participate in weekly progress updates. A student may not select a project too similar to research completed to fulfill requirements for ChE 80 or ChE 90 abc. Instructor: Vicic.

Ch/ChE 140 ab. Principles and Applications of Semiconductor Photoelectrochemistry. *9 units (3-0-6);* For course description, see Chemistry

Ch/ChE 147. Polymer Chemistry. *9 units (3-0-6);* For course description, see Chemistry

ChE/Ch 148. Polymer Physics. *9 units (3-0-6); third term.* An introduction to the physics that govern the structure and dynamics of polymeric liquids, and to the physical basis of characterization methods used in polymer science. The course emphasizes the scaling aspects of the various physical properties. Topics include conformation of a single polymer, a chain under different solvent conditions; dilute and semi-dilute solutions; thermodynamics of polymer blends and block copolymers; polyelectrolytes; rubber elasticity; polymer gels; linear viscoelasticity of polymer solutions and melts. Not offered 2025-26. Instructor: Wang.

ChE 151 ab. Physical and Chemical Rate Processes. *12 units (3-0-9); first, second terms.* The foundations of heat, mass, and momentum transfer for single and multiphase fluids will be developed. Governing differential equations; laminar flow of incompressible fluids at low and

high Reynolds numbers; forced and free convective heat and mass transfer, diffusion, and dispersion. Emphasis will be placed on physical understanding, scaling, and formulation and solution of boundary-value problems. Applied mathematical techniques will be developed and used throughout the course. Instructor: Brady.

ChE 152. Electrocatalytic Reaction Engineering. *12 units (3-0-9); third term. Prerequisites: ChE 101 or instructor's permission.* Course covers advanced topics in kinetics and reaction engineering, in the context of electrically-driven processes. The course is organized into several modules, which cover 1) the basics of electrocatalytic systems, 2) the thermodynamic basis of electrifying chemical reactions, 3) the kinetic underpinnings of electron transfer reactions, 4) the coupling of transport and kinetics in electrocatalytic systems, and 5) special topics. Instructor: Manthiram.

ChE/Ch 155. Electrified catalytic synthesis. *9 units (1.5-0-7.5); third term. Prerequisites: ChE 63ab or equivalent, ChE 103ab or equivalent, and ChE 101 or equivalent; or instructor's permission.* Discussion of fundamental and applied aspects of electron transfer steps involved in making and breaking chemical bonds at catalytic sites, with examples ranging from abiotic to biotic systems. Foundational principles are rooted in thermodynamics, kinetics, and transport. The course alternates between lecture and semi-structured student-driven projects. Not offered 2025-26. Instructor: Manthiram.

ESE/ChE 158. Aerosol Physics and Chemistry. *9 units (3-0-6);* For course description, see Environmental Science & Engineering

BE/ChE 163. Introduction to Biomolecular Engineering. *12 units (3-0-9);* For course description, see Bioengineering

ChE/Ch 164. Introduction to Statistical Thermodynamics. *9 units (3-0-6); second term. Prerequisites: Ch 21 abc or instructor's permission.* An introduction to the fundamentals and simple applications of statistical thermodynamics. Foundation of statistical mechanics; partition functions for various ensembles and their connection to thermodynamics; fluctuations; noninteracting quantum and classical gases; heat capacity of solids; adsorption; phase transitions and order parameters; linear response theory; structure of classical fluids; computer simulation methods. Instructors: Sharma, Wang..

ChE/Ch 165. Chemical Thermodynamics. *9 units (3-0-6); first term. Prerequisites: ChE 63 ab or instructor's permission.* An advanced course emphasizing the conceptual structure of modern thermodynamics and its applications. Review of the laws of thermodynamics; thermodynamic potentials and Legendre transform; equilibrium and stability conditions; metastability and phase separation kinetics; thermodynamics of single-component fluid and binary mixtures; models for solutions; phase and chemical equilibria; surface and interface thermodynamics; electrolytes and polymeric liquids. Instructors: Datta, Wang.

ChE 174. Special Topics in Transport Phenomena. *9 units (3-0-6); first term. Prerequisites: ACM 95/100 and ChE 151 ab or instructor's permission.* May be repeated for credit. Advanced problems in heat, mass, and momentum transfer. Introduction to mechanics of complex fluids; physicochemical hydrodynamics; microstructured fluids; colloidal dispersions and active matter. Other topics may be discussed depending on class needs and interests. Not offered 2025-26.

ESE/ME/EST/Ec/ChE/EE 179. Climate Change Impacts, Mitigation and Adaptation. *3 units (3-0-0);* For course description, see Environmental Science & Engineering

ESE/Ge/Bi/ChE 184. Computational Tools for Decoding Microbial Ecosystems. *9 units (3-0-6);* For course description, see Environmental Science & Engineering

ChE/BE/MedE 188. Molecular Imaging. *9 units (3-0-6); second term. Prerequisites: Ch/Bi 110, ChE 101 and ACM 95 or equivalent.* This course will cover the basic principles of biological and medical imaging technologies including magnetic resonance, ultrasound, nuclear imaging, fluorescence, bioluminescence and photoacoustics, and the design of chemical and biological probes to obtain molecular information about living systems using these modalities. Topics will include nuclear spin behavior, sound wave propagation, radioactive decay, photon absorption and scattering, spatial encoding, image reconstruction, statistical analysis, and molecular contrast mechanisms. The design of molecular imaging agents for biomarker detection, cell tracking, and dynamic imaging of cellular signals will be analyzed in terms of detection limits, kinetics, and biological effects. Participants in the course will develop proposals for new molecular imaging agents for applications such as functional brain imaging, cancer diagnosis, and cell therapy. Instructor: Shapiro.

ChE 190. Special Problems in Chemical Engineering. *Up to 9 units by arrangement; any term. Prerequisites: Instructor's permission and adviser's approval must be obtained before registering.* Special courses of readings or laboratory instruction. The student should consult a member of the faculty and prepare a definite program of reading, computation, theory and/or experiment. The student must submit a summary of progress at midterm and, at the end of the quarter, a final assignment designed in consultation with the instructor. This course may be credited only once. Grading: either grades or pass/fail, as arranged with the instructor.

ChE 280. Chemical Engineering Research. *;* Offered to Ph.D. candidates in chemical engineering. Main lines of research now in progress are covered in detail in section two.

ChE 290 abc. Chemical Engineering Seminar Course. *1 unit; first, second, third terms.* All first-year PhD degree candidates in Chemical

Engineering are required to attend at least 5 seminars each term, including all named chemical engineering seminars (Lacey, Vaughan, Economou) and additional seminars from the "Chemical Engineering Seminar" series (Thursdays at 4pm). If there are fewer than five chemical engineering seminars in a term, students may instead attend any seminar on campus on a related topic. Instructor: Vicic.

CHEMISTRY

Ch 1 ab. General Chemistry. *part a is 6 units (3-0-3) first term; part b is 9 units (4-0-5) second term; first, second terms.* First term: An introduction to general chemistry concepts with a focus on structure and bonding. Concepts will be tied to fundamental principles related to energy sustainability. Descriptions of atoms, both the physical and electronic structure with an introduction to quantum mechanics; chemical bonding models building up from molecules to extended solids; periodic trends; electrochemistry; and descriptions of states of matter. Second Term: A continuation of introduction to general chemistry concepts with a focus on chemical reactivity, and properties of complex chemical systems. Concepts related to energy, sustainability and human health will be the focus of the course with coverage of chemical thermodynamics; kinetics; non-covalent interactions; structure and bonding of organic molecules. Graded pass/fail. Instructors: See (a), Nelson (b).

IC/Ch 1 abc. Integrated Core: General Chemistry with Lab. *6 units (3-1-2); 9 units (4-2-3); 6 units (1-3-2);* For course description, see Integrated Core

Ch 3 a. Fundamental Techniques of Experimental Chemistry. *6 units (1-3-2); first, second, third terms.* Introduces the basic principles and techniques of synthesis and analysis and develops the laboratory skills and precision that are fundamental to experimental chemistry. Limited enrollment. Students must take Ch 3 in their first six terms of residence in order to be graded pass/fail. Ch 3 a and Ch 3 x both satisfy the institute's Core requirement for a Chemistry Laboratory. Instructor: Mendez.

Ch 3 x. Experimental Methods in Solar Energy Conversion. *6 units (1-3-2); first, second, third terms.* Introduces concepts and laboratory methods in chemistry and materials science centered on the theme of solar energy conversion and storage. Students will perform experiments involving optical spectroscopy, electrochemistry, laser spectroscopy, photochemistry, and photoelectrochemistry, culminating in the construction and testing of dye-sensitized solar cells. Students must take Ch 3 in their first six terms of residence in order to be graded pass/fail. Ch 3 a and Ch 3 x both satisfy the institute's Core requirement for a Chemistry Laboratory. Instructor: Mendez.

Ch 4 ab. Synthesis and Analysis of Organic and Inorganic Compounds. *9 units (1-6-2); second, third terms. Prerequisites: Ch 1 (or the equivalent) and Ch 3 a or Ch 3 x. Ch 4 a is a prerequisite for Ch 4 b. Previous or concurrent enrollment in Ch 41 is strongly recommended.* Introduction to methods of synthesis, separation, purification, and characterization used routinely in chemical research laboratories. Ch 4 a focuses on the synthesis and analysis of organic molecules; Ch 4 b focuses on the synthesis and analysis of inorganic and organometallic molecules. Ch 4 a, second term; Ch 4 b, third term. Instructor: Mendez.

Ch 5 ab. Advanced Techniques of Synthesis and Analysis. *12 units (1-9-2); first term. Prerequisites: Ch 4 ab. Ch 102 strongly recommended for Ch 5 b.* Modern synthetic chemistry. Specific experiments may change from year to year. Ch 5 a focuses on experiments illustrating the multistep syntheses of natural products. Ch 5 b focuses on the synthesis and spectroscopic characterization of coordination and organometallic complexes and their applications in organic and electrochemical catalysis. Methodology will include advanced techniques of synthesis and instrumental characterization. Terms may be taken independently. Part a not offered 2025-26. . Instructor: Agapie (b).

Ch 6 ab. Physical and Biophysical Chemistry Laboratory. *9 units (1-5-3); first term. Prerequisites: Ch 1, Ch 4 a, and Ch 21 or equivalents (may be taken concurrently).* Introduction to modern physical methods in chemistry and biology. Techniques include laser spectroscopy, microwave spectroscopy, electron spin resonance, nuclear magnetic resonance, mass spectrometry, FT-IR, fluorescence, scanning probe microscopies, and UHV surface methods. Instructor: Okumura.

Ch 7. Advanced Experimental Methods in Bioorganic Chemistry. *9 units (1-6-2); third term. Prerequisites: Ch 41 abc, Ch/Bi 110 ab, and Ch 4 a or instructor's permission.* This advanced laboratory course will provide experience in contemporary methods used in chemical biology, including polypeptide synthesis and selective labeling and imaging of glycoproteins in cells. Experiments will address amino acid protecting group strategies, biopolymer assembly and isolation, and product characterization. A strong emphasis will be placed on understanding the chemical basis underlying the successful utilization of these procedures. In addition, experiments to demonstrate the application of commercially available enzymes for useful synthetic organic transformations will be illustrated. Instructor: Hsieh-Wilson.

Ch 8. Procedures of Synthetic Chemistry for Premedical Students. *9 units (1-6-2); first term. Prerequisites: Ch 1 ab, and Ch 3 a or Ch 3 x. Previous or concurrent enrollment in Ch 41 is strongly recommended.* Introduction to methods of extraction, synthesis, separation and purification, and spectroscopic characterization of Aspirin, Dyes, and an independent project relating to medical test strips. Open to non-premedical students, as space allows. Instructor: Mendez.

Ch/ChE 9. Chemical Synthesis and Characterization for Chemical Engineering. *9 units (1-6-2); third term. Prerequisites: Ch 1 ab and Ch 3 a or Ch 3 x. Previous or concurrent enrollment in Ch 41 is strongly recommended.* Instruction in synthesis, separation, purification, and physical and spectroscopic characterization procedures of model organic compounds. Specifically looking into dye synthesis, methods of isomer identification, and an independent project relating to engineering and organic chemistry. Enrollment priority given to chemical engineering majors. Instructor: Mendez.

Ch 10 abc. Frontiers in Chemistry. *1 unit (1-0-0) first, second terms; 6 units (1-4-1) third term.; first, second, third terms. Prerequisites: Open for credit to first-year students and sophomores. Ch 10 c prerequisites are Ch 10 ab, Ch 3 a or Ch 3 x, and either Ch 1 ab, Ch 41 ab, or Ch 21 ab, and instructor's permission.* Ch 10 ab is a weekly seminar by a member of the chemistry department on a topic of current research; the topic will be presented at an informal, introductory level. Ch 10 c is a research-oriented laboratory course, which will be supervised by a chemistry faculty member. Weekly class meetings will provide a forum for participants to discuss their research projects. Graded pass/fail. Instructor: Hoelz.

Ch/Bi 11. Biochemistry Laboratory. *9 units (1-5-3); second term. Prerequisites: Ch/Bi 110 ab, Bi 8, or with permission of instructor.* The course will focus on techniques used in modern biochemistry laboratories. Students will learn how to express recombinant proteins in bacteria and purify them with various chromatography techniques. Purified proteins will be characterized by various in vitro assays. Instructors: Hoelz, Chong.

Ch 14. Chemical Equilibrium and Analysis. *9 units (3-0-6); third term.* This course has two concurrent components: (1) A physical chemistry-based approach to topics in chemical equilibrium: thermodynamics, solutions, acids, bases, and buffers, electrochemistry, and kinetics. (2) Investigation of the principles behind a suite of analytical instruments and methods in chromatography, spectroscopy, titration, and select electrochemical methods. Instructor: Dingilian.

Ch 15. Chemical Equilibrium and Analysis Laboratory. *10 units (0-6-4); third term. Prerequisites: Ch 1 ab, Ch 3 a or Ch 3 x, Ch 14, or instructor's permission.* Laboratory experiments are used to illustrate modern instrumental techniques that are currently employed in industrial and academic research. Emphasis is on determinations of chemical composition, measurement of equilibrium constants, evaluation of rates of chemical reactions, and trace-metal analysis. Instructor: Dingilian.

Ch 21 abc. Physical Chemistry. *9 units (3-0-6); first, second, third terms. Prerequisites: Ch 1 ab, Ph 2 a or Ph 12 a, Ma 2; Ma 3 is recommended. (Ph 2 a or 12 a and Ma 2 can be taken concurrently.).* Atomic and molecular quantum mechanics, spectroscopy, chemical dynamics, statistical mechanics, and thermodynamics. Instructors: Chan

(a), Wei (b), Sharma (c).

Ch 41 abc. Organic Chemistry. *9 units (4-0-5); first, second, third terms. Prerequisites: Ch 1 ab or instructor's permission.* The synthesis, structure, and reaction mechanisms of organic compounds. Instructors: Robb (a), Hsieh-Wilson (b), Stoltz (c).

Ch 80. Chemical Research. *Units in accordance with work accomplished;* Offered to B.S. candidates in chemistry. Units in accordance with work accomplished. Prerequisite: consent of research supervisor. Experimental and theoretical research requiring a report containing an appropriate description of the research work.

Ch 81. Independent Reading in Chemistry. *Units by arrangement; Prerequisites: instructor's permission.* Occasional advanced work involving reading assignments and a report on special topics. No more than 12 units in Ch 81 may be used as electives in the chemistry option.

Ch 82. Senior Thesis Research. *9 units; first, second, third terms. Prerequisites: Instructor's permission.* Three terms of Ch 82 are to be completed during the junior and/or senior year of study. At the end of the third term, students enrolled in Ch 82 will present a thesis of approximately 20 pages (excluding figures and references) to the mentor and the Chemistry Curriculum and Undergraduate Studies Committee. The thesis must be approved by both the research mentor and the CUSC. An oral thesis defense will be arranged by the CUSC in the third term for all enrollees. The first two terms of Ch 82 will be taken on a pass/fail basis, and the third term will carry a letter grade. Instructors: Agapie, staff.

Ch 90. Oral Presentation. *3 units (2-0-1); second term.* Training in the techniques of oral presentation of chemical and biochemical topics. Practice in the effective organization and delivery of technical reports before groups. Strong oral presentation is an essential skill for successful job interviews and career advancement. Graded pass/fail. Class size limited to 12 students. Instructor: Bikle.

Ch/ChE 91. Scientific Writing. *3 units (2-0-1); first, second, third terms.* Training in the writing of scientific research papers for chemists and chemical engineers. Fulfills the Institute scientific writing requirement. Instructors: Parker, Weitekamp.

Ch 101. Chemistry Tutorials. *3 units (1-0-2); third term.* Small group study and discussion on special areas of chemistry, chemical engineering, molecular biology, or biophysics. Instructors drawn from advanced graduate students and postdoctoral staff will lead weekly tutorial sessions and assign short homework assignments, readings, or discussions. Tutorials to be arranged with instructors before registration. Instructors: See, Chan.

Ch 102. Introduction to Inorganic Chemistry. *9 units (4-0-5); third term.* Structure and bonding of inorganic species with special emphasis on symmetry, spectroscopy, molecular orbital theory, ligand field theory, coordination/organometallic chemistry, and contemporary applied topics. Instructor: Hadt.

Ch 104. Intermediate Organic Chemistry. *9 units (4-0-5); second term. Prerequisites: Ch 41 abc.* A survey of selected topics beyond introductory organic chemistry, including reaction mechanisms and catalysis. Not offered 2025-26.

ChE/Ch/Bi/SEC 107. Social Media for Scientists. *9 units (3-0-6); second term.* An introduction to the use of social media for scientific communication. Social media platforms are discussed in the context of their use to professionally engage scientific communities and general audiences. Topics will include ethics, privacy, reputation management, ownership and the law, and will focus on the use and impact of social media for personal and professional career development. Lectures will include presentations by invited experts in various specialties, a number of whom will have worldwide recognition. Not offered 2025-26.

Ch/Bi 110 ab. Introduction to Biochemistry. *12 units (4-0-8); first, third terms. Prerequisites: Ch 41 abc or instructor's permission.* Lectures and recitation introducing the molecular basis of life processes. In the first term, topics will include the structure and chemical properties of biological macromolecules, molecular biology methods, and biological catalysis. The second term will cover an overview of metabolism and the biochemistry behind the transmission of genetic information. Instructors: Fianu (a), Rees (b).

Ch/Bi 111. Biochemistry of Gene Expression. *12 units (4-0-8); second term. Prerequisites: Ch/Bi 110 ab; Bi 8 and Bi 122 recommended.* Lectures and recitation on the molecular basis of biological structure and function. Emphasizes the storage, transmission, and expression of genetic information in cells. Specific topics include DNA replication, recombination, repair and mutagenesis, transcription, RNA processing, and chromatin structure. Instructors: Parker, Semlow.

Ch 112. Intermediate Inorganic Chemistry. *9 units (3-0-6); first term. Prerequisites: Ch 102 or instructor's permission.* Introduction to group theory, ligand field theory, and bonding in coordination complexes and organotransition metal compounds. Systematics of bonding, reactivity, and spectroscopy of commonly encountered classes of transition metal compounds. Instructor: Agapie.

ChE/Ch/MS 113. Squishy Engineering: Using Soft Materials to Solve Hard Problems. *9 units (3-0-6); third term. Prerequisites: ChE 63ab or equivalent, ChE 103ab or equivalent, and ChE 101 or equivalent; or instructor's permission.* The milk we drink in the morning (a colloidal dispersion), the gel we put into our hair (a polymer network), and the plaque that we try to scrub off our teeth (a biofilm)are all familiar

examples of soft materials. Such materials also hold great promise in helping to solve engineering challenges like drug delivery, water remediation, and sustainable agriculture, as well as the development of new coatings, displays, formulations, food, and biomaterials. This class will cover fundamental aspects of the science of soft materials, presented within the context of these challenges. We will also have guest speakers describe new applications of soft materials. Instructor: Datta.

Ch 117. Introduction to Electrochemistry. *9 units (3-0-6); third term.* Discussion of the fundamentals and applications of electrochemistry with an emphasis on the structure of electrode-electrolyte interfaces, mechanisms by which charge is transferred across it, kinetics of mass transfer to the interface, experimental techniques used to study electrode reactions, and application of electrochemical techniques to study materials chemistry. Topics may vary but usually include electrochemical thermodynamics, potential step waveforms, the electrical double layer, charge transfer kinetics, mass transfer kinetics, voltammetry, chronocoulometry, EIS, and RDE. Not offered 2025-26.

Ch 120 ab. Nature of the Chemical Bond. *Ch 120 a: 9 units (3-0-6), second term; Ch 120 b: (1-1-7), third term; second, third terms. Prerequisites: general exposure to quantum mechanics (e.g., Ch 21 a).* Modern ideas of chemical bonding, with an emphasis on concepts useful for predictions of structures, energetics, excited states, and properties. Part a: The quantum mechanical basis for understanding bonding, structures, energetics, dynamics, and properties of materials (polymers, ceramics, metals alloys, semiconductors, and surfaces), including transition metal and organometallic systems with a focus on chemical reactivity. The emphasis is on explaining and predicting chemical, mechanical, electrical, and thermal properties of materials in terms of atomistic concepts.; Part b: The student does an individual research project using modern quantum chemistry and molecular dynamics computer programs to calculate wavefunctions, structures, and properties of real molecules. The final is a draft for a publication. Instructor: Goddard.

Ch 121 ab. Atomic-Level Simulations of Materials and Molecules. *Ch 121 a: 9 units (3-0-6) third term; Ch 121 b (1-1-7) first term; third, first terms. Prerequisites: Ch 21 a or Ch 125 a.* Application of Atomistic-based methods to predicting the structures and properties of molecules and solids and for simulating the dynamical properties. It is aimed at experimentalists and theorists interested in learning how to apply atomistic theory to understanding structures, properties, and dynamics of molecules and solids. This course emphasizes hands-on use of modern commercial software (such as Jaguar or ORCA for QM on molecules, VASP for QM on periodic systems, and LAMMPS for MD) for practical applications and in such areas as catalysis (heterogeneous, homogeneous, and electrocatalysis), semiconductors (group IV, III-V, surfaces, defects), organo-metallics, inorganic systems (ceramics, zeolites, superconductors, and metals), biological systems (proteins, DNA, carbohydrates, lipids), and polymers (crystals, amorphous

systems, co-polymers). The first 5 weeks of Ch 121a covers the basic methods of QM and MD with hands-on applications to systems using modern software. For the midterm each student proposes a short research project to use atomistic simulations for a problem that has not yet been published. For the second 5 weeks of Ch 121a each student addresses this research project with a weekly 5-10 min presentation on progress. The final is a 5 page report on the results. In Ch 121b each student selects a more extensive research project (could be an extension of the Ch 121a project) and uses atomistic simulations to solve it. The final is a draft of a paper for publication. Instructor: Goddard.

Ch 122. Structure Determination by X-ray Crystallography. *9 units (3-0-6); first term. Prerequisites: Ch 21 abc or instructor's permission.* This course provides an introduction to small molecule X-ray crystallography. Topics include symmetry, space groups, diffraction by crystals, the direct and reciprocal lattice, Patterson and direct methods for phase determination, and structure refinement. It will cover both theoretical and applied concepts and include hands-on experience in data collection, structure solution and structure refinement. Instructor: Takase.

Ch 125 abc. The Elements of Quantum Chemistry. *9 units (3-0-6); first, second, third terms. Prerequisites: Ch 21 abc or an equivalent brief introduction to quantum mechanics.* A treatment of quantum mechanics with application to molecular and material systems. The basic elements of quantum mechanics, the electronic structure of atoms and molecules, the interactions of radiation fields and matter, and time dependent techniques relevant to spectroscopy will be covered. The course sequence prepares students for Ch 126, Ch 225, and 226. Instructors: Cushing (a), Weitekamp (b), Okumura (c).

Ch 126. Molecular Spectroscopy. *9 units (3-0-6); second term. Prerequisites: Ch 21 and Ch 125a taken concurrently, or instructor's permission.* Quantum mechanical foundations of the spectroscopy of molecules. Topics include the theory of radiation-matter interactions, applications of group theory to spectroscopy, angular momentum, magnetic resonance spectroscopy, rotational spectroscopy, vibrational spectroscopy, electronic spectroscopy, and photoelectron spectroscopy. Instructor: Winkler.

Ge/Ch 127. Nuclear Chemistry. *9 units (3-0-6);* For course description, see Geology

Ge/Ch 128. Cosmochemistry. *9 units (3-0-6);* For course description, see Geology

Ch/BMB 129. Introduction to Biophotonics. *9 units (3-0-6); first term. Prerequisites: Ch 21 abc and Ch 125 recommended.* This course will cover basic optics and introduce modern optical spectroscopy principles and microscopy techniques. Topics include molecular spectroscopy, linear and nonlinear florescence microscopy, Raman spectroscopy,

coherent microscopy, single-molecule spectroscopy, and super-resolution imaging. Instructor: Wei.

ChE/Ch/BE 130. Biomolecular Engineering Laboratory. *9 units (0-6-3); third term. Prerequisites: BE/ChE 163 or instructor's permission.* Design, construction, and characterization of engineered biological systems. Students propose and execute research projects in biomolecular engineering, synthetic biology, and genetic engineering fields. Projects will cover a broad range of molecular and cell biology, and genetics and genomics lab techniques. Instructor: Demirer.

Ch 135. Chemical Kinetics and Reaction Dynamics. *9 units (3-0-6); second term. Prerequisites: Ch 21 abc and Ch 41 abc, and Ch 125 a or equivalent, or instructor's permission.* Physical description and computations of chemical reactions and photochemistry with applications in air pollution, planetary atmospheres and condensed phases. Topics include: kinetic modeling, time-dependent quantum mechanics, rate constants, transition state theory intermolecular potentials, classical two-body elastic scattering, reactive scattering, nonadiabatic processes, statistical theories of unimolecular reactions, photochemistry, laser and molecular beam methods, theory of electron transfer, solvent effects, condensed phase dynamics, surface reactions, isotope effects. Instructor: Okumura.

ChE/Ch 137. Data Science for Chemical Systems. *9 units (2-1-6); second term. Prerequisites: Ch 41b.* Through lectures, in-class activities, and problem sets, students learn and use methods in data science to execute a project focused on a Quantitative Structure Property Relationship (QSPR). Students complete a typical research-based data science pipeline, including project definition, metric evaluation, data collection, data cleaning, exploratory data analysis, model selection, visualization, and reporting. During data cleaning and exploratory data analysis, students learn key concepts about univariate and multivariate statistics. Throughout the project, students learn about bias and fairness, the reproducibility crisis, statistical paradoxes, and more. Python is the programming language of instruction. Instructor: Vicic.

ChE/Ch 139. Challenges in Data Science for Chemical Systems. *9 units (1-0-8); third term. Prerequisites: ChE/Ch 137.* Student groups complete a one-term, data-science project that addresses an instructor-approved chemical engineering challenge. The project may be an original research idea; related to work by a research group at the Institute; an entry in a relevant national/regional contest; a response to an industry relationship; or other meaningful opportunity. There is no lecture, but students participate in weekly progress updates. A student may not select a project too similar to research completed to fulfill requirements for ChE 80 or ChE 90 abc. Instructor: Vicic.

Ch/ChE 140 ab. Principles and Applications of Semiconductor Photoelectrochemistry. *9 units (3-0-6); second term. Prerequisites: APh/EE 9 ab or instructor's permission.* The properties and

photoelectrochemistry of semiconductors and semiconductor/liquid junction solar cells will be discussed. Topics include optical and electronic properties of semiconductors; electronic properties of semiconductor junctions with metals, liquids, and other semiconductors, in the dark and under illumination, with emphasis on semiconductor/liquid junctions in aqueous and nonaqueous media. Problems currently facing semiconductor/liquid junctions and practical applications of these systems will be highlighted. Part a not offered 2025-26. . Instructor: Lewis (b).

ESE/Ge/Ch 142. Aquatic Chemistry of Natural Waters. *9 units (3-0-6);* For course description, see Environmental Science & Engineering

Ch 143. NMR Spectroscopy for Structural Identification. *9 units (3-0-6); third term. Prerequisites: Ch 41 abc.* This course will address both one-dimensional and two-dimensional techniques in NMR spectroscopy which are essential to elucidating structures of organic and organometallic samples. Dynamic NMR phenomena, multinuclear, paramagnetic and NOE effects will also be covered. An extensive survey of multipulse NMR methods will also contribute to a clear understanding of two-dimensional experiments. (Examples for Varian NMR instrumentation will be included.). Instructor: Virgil.

Ch 144 ab. Advanced Organic Chemistry. *9 units (3-0-6); first and second terms. Prerequisites: Ch 41 abc; Ch 21 abc recommended.* An advanced survey of selected topics in modern organic chemistry. Topics vary from year to year and may include structural and theoretical organic chemistry; materials chemistry; macromolecular chemistry; mechanochemistry; molecular recognition/supramolecular chemistry; reaction mechanisms; reactive intermediates; pericyclic reactions; and photochemistry. Not offered 2025-26.

Ch/Bi 145. Advanced Chemical Biology. *9 units (3-0-6); second term. Prerequisites: Ch 41 abc; Ch/Bi 110 ab recommended.* An overview of chemical approaches used to study, target, and rewire biology. Topics covered will include bioorganic chemistry, bioconjugation and bioorthogonal chemistries, fluorophores and chemical probes, crosslinking and proximity labeling, chemical genetics, new modalities in pharmacology and screening, photopharmacology, reprogramming genetic, epigenetic, and metabolic codes. Instructor: Morstein.

Ch 146. Bioorganic Chemistry of Nucleic Acids. *9 units (3-0-6); third term. Prerequisites: Ch 41 ab.* The course will examine the bioorganic chemistry of nucleic acids, including DNA and RNA structures, molecular recognition, and mechanistic analyses of covalent modification of nucleic acids. Topics include synthetic methods for the construction of DNA and RNA; separation techniques; recognition of duplex DNA by peptide analogs, proteins, and oligonucleotide-directed triple helical formation; RNA structure and RNA as catalysts (ribozymes). Not offered 2025-26.

Ch/ChE 147. Polymer Chemistry. *9 units (3-0-6); third term. Prerequisites: Ch 41 abc.* An introduction to the chemistry of polymers, including synthetic methods and mechanisms of macromolecule formation, characterization techniques, reactivity, and applications. Not offered 2025-26.

ChE/Ch 148. Polymer Physics. *9 units (3-0-6); third term.* An introduction to the physics that govern the structure and dynamics of polymeric liquids, and to the physical basis of characterization methods used in polymer science. The course emphasizes the scaling aspects of the various physical properties. Topics include conformation of a single polymer, a chain under different solvent conditions; dilute and semi-dilute solutions; thermodynamics of polymer blends and block copolymers; polyelectrolytes; rubber elasticity; polymer gels; linear viscoelasticity of polymer solutions and melts. Not offered 2025-26. Instructor: Wang.

Ch 149. Tutorial in Organic Chemistry. *6 units (2-0-4); first term. Prerequisites: Ch 41 abc and instructor's permission.* Discussion of key principles in organic chemistry, with an emphasis on reaction mechanisms and problem-solving. This course is intended primarily for first-year graduate students with a strong foundation in organic chemistry. Meets during the first three weeks of the term. Graded pass/fail. Instructor: Fu.

Ch 153 abc. Advanced Inorganic Chemistry. *9 units (3-0-6); second, third terms. Prerequisites: Ch 112 and Ch 21 abc or concurrent registration.* Ch 153 a: Topics in modern inorganic chemistry. Electronic structure, spectroscopy, and photochemistry with emphasis on examples from the research literature. Ch 153 b: Applications of physical methods to the characterization of inorganic and bioinorganic species, with an emphasis on the practical application of Moessbauer, EPR, and pulse EPR spectroscopies. Ch 153 c: Theoretical and spectroscopic approaches to understanding the electronic structure of transition metal ions. Topics in the 153 bc alternate sequence may include saturation magnetization and zero-field splitting in magnetic circular dichroism and molecular magnetism, hyperfine interactions in electron paramagnetic resonance spectroscopy, Moessbauer and magnetic Moessbauer spectroscopy, vibronic interactions in electronic absorption and resonance Raman spectroscopy, and bonding analyses using x-ray absorption and/or emission spectroscopies. Parts b, c not offered 2025-26. Instructors: Gray, Winkler (a).

Ch 154 ab. Organometallic Chemistry. *9 units (4-0-5); second term. Prerequisites: Ch 112 or equivalent.* A general discussion of the reaction mechanisms and the synthetic and catalytic uses of transition metal organometallic compounds. Part b not offered 2025-26. . Instructor: Peters (a).

ChE/Ch 155. Electrified catalytic synthesis. *9 units (1.5-0-7.5); third term. Prerequisites: ChE 63ab or equivalent, ChE 103ab or equivalent,*

and ChE 101 or equivalent; or instructor's permission. Discussion of fundamental and applied aspects of electron transfer steps involved in making and breaking chemical bonds at catalytic sites, with examples ranging from abiotic to biotic systems. Foundational principles are rooted in thermodynamics, kinetics, and transport. The course alternates between lecture and semi-structured student-driven projects. Not offered 2025-26. Instructor: Manthiram.

ChE/Ch 164. Introduction to Statistical Thermodynamics. *9 units (3-0-6); second term. Prerequisites: Ch 21 abc or instructor's permission.* An introduction to the fundamentals and simple applications of statistical thermodynamics. Foundation of statistical mechanics; partition functions for various ensembles and their connection to thermodynamics; fluctuations; noninteracting quantum and classical gases; heat capacity of solids; adsorption; phase transitions and order parameters; linear response theory; structure of classical fluids; computer simulation methods. Instructors: Sharma, Wang..

ChE/Ch 165. Chemical Thermodynamics. *9 units (3-0-6); first term. Prerequisites: ChE 63 ab or instructor's permission.* An advanced course emphasizing the conceptual structure of modern thermodynamics and its applications. Review of the laws of thermodynamics; thermodynamic potentials and Legendre transform; equilibrium and stability conditions; metastability and phase separation kinetics; thermodynamics of single-component fluid and binary mixtures; models for solutions; phase and chemical equilibria; surface and interface thermodynamics; electrolytes and polymeric liquids. Instructors: Datta, Wang.

BMB/Bi/Ch 170. Biochemistry and Biophysics of Macromolecules and Molecular Assemblies. *9 units (3- 0-6);* For course description, see Biochemistry & Molecular Biophysics

ESE/Ge/Ch 171. Atmospheric Chemistry I. *9 units (3-0-6);* For course description, see Environmental Science & Engineering

BMB/Bi/Ch 173. Biophysical/Structural Methods. *9 units (3-0-6);* For course description, see Biochemistry & Molecular Biophysics

BMB/Bi/Ch 174. Macromolecular Machines of the Central Dogma. *6 units (3-0-3);* For course description, see Biochemistry & Molecular Biophysics

ESE/Ch 176. Environmental Physical Organic Chemistry. *9 units (3-0-6);* For course description, see Environmental Science & Engineering

BMB/Ch 178. Macromolecular Function: kinetics, energetics, and mechanisms. *9 units (3-0-6);* For course description, see Biochemistry & Molecular Biophysics

Ch 180. Chemical Research. *Units by arrangement;* Offered to M.S. candidates in chemistry. Graded pass/fail.

BMB/Ch 202 abc. Biochemistry Seminar Course. *1 unit;* For course description, see Biochemistry & Molecular Biophysics

Ch 212. Bioinorganic Chemistry. *9 units (3-0-6); Prerequisites: Ch 112 and Ch/Bi 110 or equivalent.* Current topics in bioinorganic chemistry will be discussed, including metal storage and regulation, metalloenzyme structure and reactions, biological electron transfer, metalloprotein design, and metal-nucleic acid interactions and reactions. Not offered 2025-26.

Ch 213 abc. Advanced Ligand Field Theory. *12 units (1-0-11); first, second, third terms. Prerequisites: Ch 21 abc or concurrent registration.* A tutorial course of problem solving in the more advanced aspects of ligand field theory. Recommended only for students interested in detailed theoretical work in the inorganic field. Instructor: Gray.

Ch 225. Advanced Quantum Chemistry. *9 units (3-0-6); Prerequisites: Ch 125 ab or equivalent, or permission of instructors.* The electronic structure of atoms and molecules, the interactions of radiation fields and matter, scattering theory, and reaction rate theory. Not offered 2025-26.

Ch 226. Optical and Nonlinear Spectroscopy. *9 units (3-0-6); third term. Prerequisites: Ch 125 ab, or equivalent instruction in quantum mechanics.* Quantum mechanical foundations of optical spectroscopy as applied to chemical and material systems. Topics include optical properties of materials, nonlinear and quantum optics, and multidimensional spectroscopy. Instructors: Blake, Cushing.

BMB/Ch 230. Macromolecular Structure Determination with Modern X-ray Crystallography Methods. *12 units (2-4-6);* For course description, see Biochemistry & Molecular Biophysics

Ch 242 ab. Chemical Synthesis. *9 units (4-0-5); first term. Prerequisites: Ch 41 abc.* An integrated approach to synthetic problem solving featuring an extensive review of modern synthetic reactions with concurrent development of strategies for synthesis design. Part a will focus on the application of modern methods of stereocontrol in the construction of stereochemically complex acyclic systems. Part b will focus on strategies and reactions for the synthesis of cyclic systems. Part b not offered 2025-26. . Instructor: Stoltz (a).

Ch 247. Organic Reaction Mechanisms. *9 units (3-0-6); Prerequisites: Ch 41 abc, Ch 242 a recommended.* This course will discuss and uncover useful strategies and tactics for approaching complex reaction mechanisms prevalent in organic reactions. Topics include: cycloaddition chemistry, rearrangements, radical reactions, metal-catalyzed processes, photochemical reactions among others. Recommended only for students interested in advanced study in organic

chemistry or related fields. Not offered 2025-26.

Ch 250. Advanced Topics in Chemistry. *3 units;* Content will vary from year to year; topics are chosen according to the interests of students and staff. Visiting faculty may present portions of this course. In Spring 2020 the class will be a seminar course in pharmaceutical chemistry with lectures by industrial researchers from both discovery (medicinal chemistry) and development (process chemistry) departments. Not offered 2025-26.

Ch 251. Advanced Topics in Chemical Biology. *9 units (3-0-6); Prerequisites: Ch 145 or 146 or consent of the instructor.* Advanced Topics in Chemical Biology. Hours and units to be arranged. Content will vary from year to year; topics are chosen according to the interests of students and staff. Not offered 2025-26.

Ch 252. Advanced Topics in Chemical Physics. *Hours and units to be arranged; first term.* Content will vary from year to year; topics are chosen according to the interests of students and staff. Instructor: Okumura.

Ch/Bi 253. Advanced Topics in Biochemistry. *6 units (2-0-4);* Hours and units to be arranged. Content will vary from year to year; topics are chosen according to the interests of students and staff. Not offered 2025-26.

Ch 279. Rotations in Chemistry. *Variable units as arranged with the advising faculty member; first, second, third terms.* By arrangement with members of the faculty, properly qualified graduate students will have the opportunity to engage in a short-term research project culminating in a presentation to their peers enrolled in the course and participating laboratories. (Pass-Fail only).

Ch 280. Chemical Research. *Hours and units by arrangement;* By arrangement with members of the faculty, properly qualified graduate students are directed in research in chemistry.

CIVIL ENGINEERING

CE 100. Special Topics in Civil Engineering. *Units to be based upon work done, any term;* Special problems or courses arranged to meet the needs of first-year graduate students or qualified undergraduate students. Graded pass/fail.

Ae/APh/CE/ME 101 abc. Fluid Mechanics. *9 units (3-0-6);* For course description, see Aerospace

Ae/AM/CE/ME 102 abc. Mechanics of Structures and Solids. *9 units (3-0-6);* For course description, see Aerospace

CE/Ae/AM 108. Computational Mechanics. *9 units (3-5-1); first, second terms. Prerequisites: Ae/AM/ME/CE 102 abc or Ae/GE/ME 160 ab, or instructor's permission.* Numerical methods and techniques for solving initial boundary value problems in continuum mechanics (from heat conduction to statics and dynamics of solids and structures). Finite difference methods, direct methods, variational methods, finite elements in small strains and at finite deformation for applications in structural mechanics and solid mechanics. Solution of the partial differential equations of heat transfer, solid and structural mechanics, and fluid mechanics. Transient and nonlinear problems. Computational aspects and development and use of finite element code. Not offered 2025-26.

ME/CE/Ge/ESE 146. Computational Methods for Flow in Porous Media. *9 units (3-0-6);* For course description, see Mechanical Engineering

AM/CE/ME 150 abc. Graduate Engineering Seminar. *1 unit;* For course description, see Applied Mechanics

AM/CE 151. Dynamics and Vibration. *9 units (3-0-6);* For course description, see Applied Mechanics

CE 160 ab. Structural and Earthquake Engineering. *9 units (3-0-6); second, third terms.* Matrix structural analysis of the static and dynamic response of structural systems, Newmark time integration, Newton-Raphson iteration methodology for the response of nonlinear systems, stability of iteration schemes, static and dynamic numerical analysis of planar beam structures (topics include the development of stiffness, mass, and damping matrices, material and geometric nonlinearity effects, formulation of a nonlinear 2-D beam element, uniform and nonuniform earthquake loading, soil-structure interaction, 3-D beam element formulation, shear deformations, and panel zone deformations in steel frames, and large deformation analysis), seismic design and analysis of steel moment frame and braced frame systems, steel member behavior (topics include bending, buckling, torsion, warping, and lateral torsional buckling, and the effects of residual stresses), reinforced concrete member behavior (topics include bending, shear, torsion, and PMM interaction), and seismic design requirements for reinforced concrete structures. Not offered 2025-26.

Ae/CE 165 ab. Mechanics of Composite Materials and Structures. *9 units (2-2-5);* For course description, see Aerospace

ME/CE/Ge 174. Mechanics of Rocks. *9 units (3-0-6);* For course description, see Mechanical Engineering

CE 180. Experimental Methods in Earthquake Engineering. *9 units (1-5-3); first term. Prerequisites: AM/CE 151 abc or equivalent.* Laboratory work involving calibration and performance of basic transducers suitable for the measurement of strong earthquake ground

motion, and of structural response to such motion. Study of principal methods of dynamic tests of structures, including generation of forces and measurement of structural response. Not offered 2025-26.

CE 200. Advanced Work in Civil Engineering. *6 or more units as arranged; any term.* A faculty mentor will oversee a student proposed, independent research or study project to meet the needs of graduate students. Graded pass/fail. The consent of a faculty mentor and a written report is required for each term.

CE 201. Advanced Topics in Civil Engineering. *9 units (3-0-6); third term.* The faculty will prepare courses on advanced topics to meet the needs of graduate students. Instructor: Andrade.

Ae/AM/CE/ME 214. Computational Solid Mechanics. *9 units (3-5-1);* For course description, see Aerospace

Ae/CE 221. Space Structures. *9 units (3-0-6);* For course description, see Aerospace

Ge/Bi/ESE/CE 249. Stable Isotopes: Ecological and Environmental Applications. *9 units (3-3-3);* For course description, see Geology

AM/CE/ME 252. Linear and Nonlinear Waves in Structured Media. *9 units (2-1-6);* For course description, see Applied Mechanics

Ae/AM/CE/ME/Ge 265 ab. Static and Dynamic Failure of Brittle Solids and Interfaces, from the Micro to the Mega. *9 units (3-0-6);* For course description, see Aerospace

CE 300. Research in Civil Engineering. *Hours and units by arrangement;* Research in the field of civil engineering. By arrangements with members of the staff, properly qualified graduate students are directed in research.

COMPUTATION & NEURAL SYSTEMS

CNS 99 abc. Senior Thesis. *9 or more units per term with a total of at least 27 units; first, second, third terms. Prerequisites: Senior standing and instructor's permission.* Research in the broader CNS range, supervised by a CNS faculty member, culminating in a thesis. The topic is determined by the research adviser and the student. The first and second terms are taken pass/fail and require a written report at the end of each term. The third term is taken on grades and requires completion of a thesis and final presentation. The last two terms must be completed in the final year of study. Total units may be arranged with the advising faculty member. Optional requirement for a BS degree (CNS major). It can be replaced by equivalent research or elective units. Instructor: Staff.

CNS 100. Introduction to Computation and Neural Systems. *1 unit; first term.* This course is designed to introduce undergraduate and first-year CNS graduate students to the wide variety of research being undertaken by CNS faculty. Topics from all the CNS research labs are discussed and span the range from biology to engineering. Graded pass/fail. Instructor: Siapas.

CNS/Psy/Bi 102 a. Social and Decision Neuroscience. *9 units (3-0-6); second term. Prerequisites: NB/Bi/CNS 150 and CNS/Bi/Ph/CS/NB 187, or instructor's permission.* Introduction to the computations made by the brain during economic and social decision making and their neural substrates. Part a: Introduction to social and decision neuroscience. Neural substrates of reward and reinforcement learning. Unconscious and conscious processing. The neural basis of emotion. Goal-directed and habit learning. The neural substrates of facial processing. Instructor: Adolphs/O'Doherty.

CNS/Psy/Bi 102 b. Social and Decision Neuroscience. *9 units (3-0-6); third term. Prerequisites: NB/Bi/CNS 150 and CNS/Bi/Ph/CS/NB 187, or instructor's permission.* Introduction to the computations made by the brain during economic and social decision making and their neural substrates. Part b: History and mechanisms of reinforcement. Memory and valuation. Neural repurposing. Mentalizing and strategic thinking. Neural bases of prosociality, risky choice and delay discounting. Mathematical economic-style theories of neural circuits. Not offered 2025-26. Instructor: Camerer.

Psy/CNS 105 ab. Frontiers in Neuroeconomics. *5 units (1.5-0-3.5);* For course description, see Psychology

Psy/CNS 130. Introduction to Human Memory. *9 units (3-0-6);* For course description, see Psychology

Psy/CNS 132. Computational Reinforcement-learning in Biological and Non-biological Systems. *9 units (3-0-6);* For course description, see Psychology

Ge/Bi/BE/CNS/ESE 147. Challenges and Opportunities in Quantitative Ecology. *6 units (6-0-0);* For course description, see Geology

EE/CNS/CS 148 ab. Deep Learning. *12 units (3-0-9);* For course description, see Electrical Engineering

NB/Bi/CNS 150. Introduction to Neuroscience. *10 units (4-0-6);* For course description, see Neurobiology

NB/Bi/CNS 152. Neural Circuits and Physiology of Homeostatic Regulation. *6 units (2-0-4);* For course description, see Neurobiology

NB/Bi/CNS 154. Principles of Neuroscience. *9 units (3-0-6);* For course description, see Neurobiology

CMS/CS/CNS/EE/IDS 155. Machine Learning & Data Mining. *12 units (3-3-6);* For course description, see Computing and Mathematical Sciences

CS/CNS/EE 156 ab. Learning Systems. *9 units (3-1-5);* For course description, see Computer Science

Bi/CNS 158. Vertebrate Evolution. *9 units (3-0-6);* For course description, see Biology

CS/CNS/EE/IDS 159. Advanced Topics in Machine Learning. *9 units (3-0-6);* For course description, see Computer Science

NB/Bi/CNS 162. Cellular and Systems Neuroscience Laboratory. *12 units (2-4-6);* For course description, see Neurobiology

NB/Bi/CNS 163. The Biological Basis of Neural Disorders. *6 units (3-0-3);* For course description, see Neurobiology

NB/Bi/CNS 164. Tools of Neurobiology. *9 units (3-0-6);* For course description, see Neurobiology

CS/CNS/EE/IDS 165. Foundations of Machine Learning and Statistical Inference. *12 units (3-3-6);* For course description, see Computer Science

PI/CNS/NB/Bi/Psy 167. Consciousness. *9 units (3-0-6);* For course description, see Philosophy

CS/CNS 171. Computer Graphics Laboratory. *12 units (3-6-3);* For course description, see Computer Science

CS/CNS 174. Computer Graphics Projects. *12 units (3-6-3);* For course description, see Computer Science

CNS/Bi/Psy/NB 176. Cognition. *9 units (4-0-5); Third term.* The cornerstone of current progress in understanding the mind, the brain, and the relationship between the two is the study of human and animal cognition. This course will provide an in-depth survey and analysis of behavioral observations, theoretical accounts, computational models, patient data, electrophysiological studies, and brain-imaging results on mental capacities such as attention, memory, emotion, object representation, language, and cognitive development. Given in alternate years; not offered 2025-26. Instructor: Shimojo.

CNS 180. Research in Computation and Neural Systems. *Units by arrangement with faculty;* Offered to precandidacy students.

CNS/Bi/EE/CS/NB 186. Vision: From Computational Theory to Neuronal Mechanisms. *12 units (4-4-4); second term.* Lecture,

laboratory, and project course aimed at understanding visual information processing, in both machines and the mammalian visual system. The course will emphasize an interdisciplinary approach aimed at understanding vision at several levels: computational theory, algorithms, psychophysics, and hardware (i.e., neuroanatomy and neurophysiology of the mammalian visual system). The course will focus on early vision processes, in particular motion analysis, binocular stereo, brightness, color and texture analysis, visual attention and boundary detection. Students will be required to hand in approximately three homework assignments as well as complete one project integrating aspects of mathematical analysis, modeling, physiology, psychophysics, and engineering. Given in alternate years; offered 2025-26. Instructors: Meister, Perona, Shimojo.

CNS/Bi/Ph/CS/NB 187. Neural Computation. *9 units (3-0-6); third term. Prerequisites: introductory neuroscience (Bi 150 or equivalent); mathematical methods (Bi 195 or equivalent); scientific programming.* This course aims at a quantitative understanding of how the nervous system computes. The goal is to link phenomena across scales from membrane proteins to cells, circuits, brain systems, and behavior. We will learn how to formulate these connections in terms of mathematical models, how to test these models experimentally, and how to interpret experimental data quantitatively. The concepts will be developed with motivation from some of the fascinating phenomena of animal behavior, such as: aerobatic control of insect flight, precise localization of sounds, sensing of single photons, reliable navigation and homing, rapid decision-making during escape, one-shot learning, and large-capacity recognition memory. Instructor: Meister.

BE/CS/CNS/Bi 191 ab. Biomolecular Computation. *9 units; part a (3-0-6) and part b (2-4-3);* For course description, see Bioengineering

Bi/CNS/NB 195. Mathematics in Biology. *9 units (3-0-6);* For course description, see Biology

BE/Bi/CNS/NB 197. Mentoring and Outreach. *Units to be arranged, up to 12 units per year;* For course description, see Bioengineering

NB/Bi/CNS 216. Behavior of Mammals. *6 units (2-0-4);* For course description, see Neurobiology

NB/Bi/CNS 220. Genetic Dissection of Neural Circuit Function. *6 units (2-0-4);* For course description, see Neurobiology

Bi/CNS/BE/NB 230. Optogenetic and CLARITY Methods in Experimental Neuroscience. *9 units (3-2-4);* For course description, see Biology

Bi/BE/CNS/NB 241. Spatial Genomics. *9 units (1-8-0);* For course description, see Biology

CNS/Bi/NB 247. Cerebral Cortex. *6 units (2-0-4); second term. Prerequisites: NB/Bi/CNS 150 or equivalent.* A general survey of the structure and function of the cerebral cortex. Topics include cortical anatomy, functional localization, and newer computational approaches to understanding cortical processing operations. Motor cortex, sensory cortex (visual, auditory, and somatosensory cortex), association cortex, and limbic cortex. Emphasis is on using animal models to understand human cortical function and includes correlations between animal studies and human neuropsychological and functional imaging literature. Given in alternate years; not offered 2025-26. Instructor: Andersen.

NB/Bi/CNS 250 c. Topics in Systems Neuroscience. *9 units (3-0-6);* For course description, see Neurobiology

CNS 251. Human Brain Mapping: Theory and Practice. *9 units (2-1-6); second term.* A course in functional brain imaging. An overview of contemporary brain imaging techniques, usefulness of brain imaging compared to other techniques available to the modern neuroscientist. Review of what is known about the physical and biological bases of the signals being measured. Design and implementation of a brain imaging experiment and analysis of data (with a particular emphasis on fMRI). Instructor: O'Doherty.

Psy/Bi/CNS 255. Topics in Emotion and Social Cognition. *9 units (3-0-6);* For course description, see Psychology

CNS/Bi/NB 256. Brain-machine interfaces. *6 units (2-0-4); third term.* A brain-machine interface (BMI) records neural activity, decodes the intent of the participant, and generates control signals to operate assistive devices. Bi-directional BMIs can write signals back into the brain though electrical stimulation based on the recorded neural activity. These neurotechnologies have been advancing rapidly with therapeutic potential for several neurological diseases and disorders. Through lectures and reviews of the literature, the course will cover motor BMIs for robotics and communication, cognitive neural prosthetics, stimulation to restore sensation, and different invasive and non-invasive recording and stimulation technologies. Given in alternate years; offered 2025-26. Instructor: Andersen.

CNS 280. Research in Computation and Neural Systems. *Hours and units by arrangement;* For graduate students admitted to candidacy in computation and neural systems.

SS/Psy/CNS 285. Topics in Social, Cognitive, and Decision Sciences. *3 units (1.5-0-1.5);* For course description, see Social Science

CNS/Bi 286 abc. Special Topics in Computation and Neural Systems. *Units to be arranged; first, second, third terms.* Students may register with permission of the responsible faculty member.

COMPUTER SCIENCE

CS 1. Introduction to Computer Programming. *9 units (3-0-6); first, third terms.* A course on computer programming emphasizing the program design process and pragmatic programming skills. We will primarily use the Python programming language and no previous programming experience is needed or expected. The course will include data types, variables, assignment, control structures, functions, scoping, compound data, string processing, modules, basic input/output (terminal and file), as well as more advanced topics such as recursion, exception handling and object-oriented programming. We will also teach program development, debugging, and how to write documentation. Projects will include problems drawn from many different areas such as physics, chemistry, math, and games. At the end of the course, students will be ready to take more advanced courses in the computer science option. Instructor: Blank.

CS 1 x. Intermediate Computer Programming. *6 units (2-2-2); first term. Prerequisites: Enrollment by instructor permission only.* Students must be placed into this course via the CS placement test. An intermediate course on computer programming emphasizing the program design process and pragmatic programming skills. It will use the Java programming language and will assume previous programming experience such as an AP CS A course. Material will focus on more advanced topics such as recursion, exception handling and object-oriented programming. Program development and maintenance skills including debugging, testing, and documentation will also be taught. Assignments will include problems drawn from fields such as graphics, numerics, networking, and games. At the end of the course, students will be ready to take more advanced courses in the computer science option. Instructor: Vanier.

CS 2. Introduction to Programming Methods. *9 units (3-5-1); second term. Prerequisites: CS 1 or equivalent.* CS 2 is a demanding course in programming languages and computer science. Topics covered include data structures, including lists, trees, and graphs; implementation and performance analysis of fundamental algorithms; algorithm design principles, in particular recursion and dynamic programming; Heavy emphasis is placed on the use of compiled languages and development tools, including source control and debugging. The course includes weekly laboratory exercises and projects covering the lecture material and program design. The course is intended to establish a foundation for further work in many topics in the computer science option. Instructor: Blank.

CS 3. Introduction to Software Design. *9 units (2-6-1); third term. Prerequisites: CS 2 or equivalent.* CS 3 is a practical introduction to designing large programs in a low-level language. Heavy emphasis is placed on documentation, testing, and software architecture. Students will work in teams in two 5-week long projects. In the first half of the

course, teams will focus on testing and extensibility. In the second half of the course, teams will use POSIX APIs, as well as their own code from the first five weeks, to develop a large software deliverable. Software engineering topics covered include code reviews, testing and testability, code readability, API design, refactoring, and documentation. Not offered 2025-26. Instructor: Staff.

CS 3 x. Introduction to Software Design in C. *6 units (2-1-3); third term. Prerequisites: CS 2.* CS 3 is a practical introduction to the C programming language. Throughout the term, students will work individually on one large pre-defined project that is separated into individual chunks that increase in complexity. Heavy emphasis is placed on self-ownership of code, learning the C programming language, debugging, and writing readable software. Prior experience with the C programming language is NOT expected or assumed. Instructors: Ordentlich, Blank.

CS 4. Fundamentals of Computer Programming. *9 units (3-4-2); second term. Prerequisites: CS 1 or instructor's permission.* This course gives students the conceptual background necessary to construct and analyze programs, which includes specifying computations, understanding evaluation models, and using major programming language constructs (functions and procedures, conditionals, recursion and looping, scoping and environments, compound data, side effects, higher-order functions and functional programming, and object-oriented programming). It emphasizes key issues that arise in programming and in computation in general, including time and space complexity, choice of data representation, and abstraction management. This course is intended for students with some programming background who want a deeper understanding of the conceptual issues involved in computer programming. Instructor: Vanier.

Ma/CS 6/106 abc. Introduction to Discrete Mathematics. *9 units (3-0-6);* For course description, see Mathematics

EE/CS 10 ab. Introduction to Digital Logic and Embedded Systems. *6 units (2-3-1);* For course description, see Electrical Engineering

CS 11. Computer Language Lab. *3 units (0-3-0); second and third terms. Prerequisites: CS 1 or instructor's permission.* A self-paced lab that provides students with extra practice and supervision in transferring their programming skills to a particular programming language. The course can be used for any language of the student's choosing, subject to approval by the instructor. A series of exercises guide students through the pragmatic use of the chosen language, building their familiarity, experience, and style. More advanced students may propose their own programming project as the target demonstration of their new language skills. This course is available for undergraduate students only. Graduate students should register for CS 111. CS 11 may be repeated for credit of up to a total of nine units. Instructor: Vanier.

CS 12. Student-Taught Topics in Computing. *variable units between 1 and 9; first, second, third terms. Prerequisites: CS 1 or instructor's permission.* Each section covers a topic in computing with associated sets or projects. Sections are designed and taught by an undergraduate student under the supervision of a CMS faculty member. CS 12 may be repeated for credit of up to a total of nine units. Instructor: Staff.

CS 13. Mathematical Foundations of Computer Science. *9 units (3-0-6); third term. Prerequisites: CS 1.* This course introduces key mathematical concepts used in computer science, and in particular it prepares students for proof-based CS courses such as CS 21 and CS 38. Mathematical topics are illustrated via applications in Computer Science. CS 1 is a co-requisite as there will be a small number of programming assignments. The course covers basic set theory, induction and inductive structures (e.g., lists and trees), asymptotic analysis, and elementary combinatorics, number theory, and graph theory. Applications include number representation, basic cryptography, basic algorithms on trees, numbers, and polynomials, social network graphs, compression, and simple error-correcting codes. Instructor: Blank.

CS 18. Software Design Practicum. *6 units (1-0-5); third term. Prerequisites: CS 3(c) or instructor's permission.* CS 18 is a practical introduction to designing large programs in a low-level language. Heavy emphasis is placed on group work, documentation, testing, and software architecture. Students will work in throughout the term to create their own physics engine and open-ended game using the C programming language. Software engineering topics covered include code reviews, testing and testability, code readability, API design, refactoring, and documentation. Prior experience with the C programming language at the level of CS 3(c) is required and assumed. Instructors: Ordentlich, Blank.

CS 19 ab. Introduction to Computer Science in Industry. *2 units (1-0-1); first term.* This course will introduce students to CS in industry through weekly overview talks by alums and engineers in industry. It is aimed at first and second year undergraduates. Others may wish to take the course to gain an understanding of the scope of computer science in industry. Additionally students will complete short weekly assignments aimed at preparing them for interactions with industry. Graded pass/fail. Part b not offered 2025-26. Instructor: Ralph.

CS 21. Decidability and Tractability. *9 units (3-0-6); second term. Prerequisites: CS 2 (may be taken concurrently).* This course introduces the formal foundations of computer science, the fundamental limits of computation, and the limits of efficient computation. Topics will include automata and Turing machines, decidability and undecidability, reductions between computational problems, and the theory of NP-completeness. Instructor: Umans.

CS 22. Data Structures & Parallelism. *9 units (3-6-0); second term. Prerequisites: CS 2 or instructor's permission.* CS 22 is a demanding course that covers implementation, correctness, and analysis of data structures and some parallel algorithms. This course is intended for students who have already taken a data structures course at the level of CS 2. Topics include implementation and analysis of skip lists, trees, hashing, and heaps as well as various algorithms (including string matching, parallel sorting, parallel prefix). The course includes weekly written and programming assignments covering the lecture material. Not offered 2025-26. Instructor: Staff.

CS 24. Introduction to Computing Systems. *9 units (3-3-3); first term. Prerequisites: CS 2 and CS 3.* Basic introduction to computer systems, including hardware-software interface, computer architecture, and operating systems. Course emphasizes computer system abstractions and the hardware and software techniques necessary to support them, including virtualization (e.g., memory, processing, communication), dynamic resource management, and common-case optimization, isolation, and naming. Instructors: Ordentlich, Blank.

CS 38. Algorithms. *9 units (3-0-6); third term. Prerequisites: CS 2; Ma/CS 6 a or Ma 121 a; and CS 21.* This course introduces techniques for the design and analysis of efficient algorithms. Major design techniques (the greedy approach, divide and conquer, dynamic programming, linear programming) will be introduced through a variety of algebraic, graph, and optimization problems. Methods for identifying intractability (via NP-completeness) will be discussed. Instructors: Mahadev, Ralph.

CS 42. Computer Science Education in K-14 Settings. *6 units (2-2-2); second term.* This course will focus on computer science education in K-14 settings. Students will gain an understanding of the current state of computer science education within the United States, develop curricula targeted at students from diverse backgrounds, and gain hands on teaching experience. Through readings from educational psychology and neuropsychology, students will become familiar with various pedagogical methods and theories of learning, while applying these in practice as part of a teaching group partnered with a local school or community college. Each week students are expected to spend about 2 hours teaching, 2 hours developing curricula, and 2 hours on readings and individual exercises. Pass/Fail only. May not be repeated. Instructors: Wierman, Ralph.

CS/EE/ME 75 abc. Multidisciplinary Systems Engineering. *3 units (2-0-1), 6 units (2-0-4), or 9 units (2-0-7) first term; 6 units (2-3-1), 9 units (2-6-1), or 12 units (2-9-1) second and third terms; first, second, third terms.* This course presents the fundamentals of modern multidisciplinary systems engineering in the context of a substantial design project. Students from a variety of disciplines will conceive, design, implement, and operate a system involving electrical, information, and mechanical engineering components. Specific tools will

be provided for setting project goals and objectives, managing interfaces between component subsystems, working in design teams, and tracking progress against tasks. Students will be expected to apply knowledge from other courses at Caltech in designing and implementing specific subsystems. During the first two terms of the course, students will attend project meetings and learn some basic tools for project design, while taking courses in CS, EE, and ME that are related to the course project. During the third term, the entire team will build, document, and demonstrate the course design project, which will differ from year to year. First-year undergraduate students must receive permission from the lead instructor to enroll. Not offered 2025-26. Instructor: Staff.

CS 80 abc. Undergraduate Thesis. *9 units; first, second, third terms. Prerequisites: instructor's permission, which should be obtained sufficiently early to allow time for planning the research.* Individual research project, carried out under the supervision of a member of the computer science faculty (or other faculty as approved by the computer science undergraduate option representative). Projects must include significant design effort. Written report required. Open only to upperclass students. Not offered on a pass/fail basis. Instructor: Staff.

CS 81 abc. Undergraduate Projects in Computer Science. *Units are assigned in accordance with work accomplished; Prerequisites: Consent of supervisor is required before registering.* Supervised research or development in computer science by undergraduates. The topic must be approved by the project supervisor, and a formal final report must be presented on completion of research. This course can (with approval) be used to satisfy the project requirement for the CS major. Graded pass/fail. Instructor: Staff.

CS 82. Course Development in Computer Science. *Units are assigned in accordance with work accomplished; first, second, and third terms. Prerequisites: Consent of supervisor is required before registering.* Supervised course or project development in computer science by undergraduates. The topic must be approved by the project supervisor. This course can (with approval) be used to satisfy the project requirement for the CS major. Graded pass/fail. Instructor: Staff.

CS 90. Undergraduate Reading in Computer Science. *Units are assigned in accordance with work accomplished; Prerequisites: Consent of supervisor is required before registering.* Supervised reading in computer science by undergraduates. The topic must be approved by the reading supervisor, and a formal final report must be presented on completion of the term. Graded pass/fail. Instructor: Staff.

CS 99. Pedagogy in Computer Science. *3 units (1-0-2); third term.* This course is a highly interactive overview of teaching strategies that foster deep learning in an inclusive classroom environment in Computer Science courses. The course does this by providing theory and practice through authentic teaching and presenting experiences. Throughout the course, we introduce a variety of topics including, but not limited to

research in CS education, active learning, and how to create an inclusive classroom. Graded with letters. Instructors: Blank, Bryant.

CS 101. Special Topics in Computer Science. *Units in accordance with work accomplished; Offered by announcement. Prerequisites: specified by instructor.* The topics covered vary from year to year, depending on the students and staff. Primarily for undergraduates. Instructor: Staff.

CS 102 abc. Seminar in Computer Science. *3, 6, or 9 units as arranged with the instructor;* Instructor's permission required. Instructor: Staff.

CS 103 abc. Reading in Computer Science. *3, 6, or 9 units as arranged with the instructor;* Instructor's permission required. Instructor: Staff.

HPS/PI/CS 110. Causation and Explanation. *9 units (3-0-6);* For course description, see History and Philosophy of Science

CS 111. Graduate Programming Practicum. *3 units (0-3-0); second and third terms. Prerequisites: CS 1 or equivalent.* A self-paced lab that provides students with extra practice and supervision in transferring their programming skills to a particular programming language. The course can be used for any language of the student's choosing, subject to approval by the instructor. A series of exercises guide the student through the pragmatic use of the chosen language, building their familiarity, experience, and style. More advanced students may propose their own programming project as the target demonstration of their new language skills. This course is available for graduate students only. CS 111 may be repeated for credit of up to a total of nine units. Undergraduates should register for CS 11. Instructor: Vanier.

Ec/ACM/CS 112. Bayesian Statistics. *9 units (3-0-6);* For course description, see Economics

CS 115. Functional Programming. *9 units (3-4-2); third term. Prerequisites: CS 1 and CS 4.* This course is a both a theoretical and practical introduction to functional programming, a paradigm which allows programmers to work at an extremely high level of abstraction while simultaneously avoiding large classes of bugs that plague more conventional imperative and object-oriented languages. The course will introduce and use the lazy functional language Haskell exclusively. Topics include: recursion, first-class functions, higher-order functions, algebraic data types, polymorphic types, function composition, point-free style, proving functions correct, lazy evaluation, pattern matching, lexical scoping, type classes, modules, and monads. Some advanced topics such as monad transformers, parser combinators, dynamic typing, and existential types are also covered. Instructor: Vanier.

CS 116. Reasoning about Program Correctness. *9 units (3-0-6); first term. Prerequisites: CS 1 or equivalent.* This course presents the use of logic and formal reasoning to prove the correctness of sequential and

concurrent programs. Topics in logic include propositional logic, basics of first-order logic, and the use of logic notations for specifying programs. The course presents a programming notation and its formal semantics, Hoare logic and its use in proving program correctness, predicate transformers and weakest preconditions, and fixed-point theory and its application to proofs of programs. Not offered 2025-26. Instructor: Staff.

Ma/CS 117 abc. Computability Theory. *9 units (3-0-6);* For course description, see Mathematics

CS 118. Automata-Theoretic Software Analysis. *9 units (3-3-3); second term.* An introduction to the use of automata theory in the formal analysis of both concurrent and sequentially executing software systems. The course covers the use of logic model checking with linear temporal logic and interactive techniques for property-based static source code analysis. Not offered 2025-26. Instructor: Staff.

EE/CS 119 abc. Advanced Digital Systems Design. *9 units (3-3-3) first, second term; 9 units (1-8-0) third term;* For course description, see Electrical Engineering

CS/Ph 120. Quantum Cryptography. *9 units (3-0-6); first term. Prerequisites: Ma 1 b, Ph 2 b or Ph 12 b, CS 21, CS 38 or equivalent recommended (or instructor's permission).* This course is an introduction to quantum cryptography: how to use quantum effects, such as quantum entanglement and uncertainty, to implement cryptographic tasks with levels of security that are impossible to achieve classically. The course covers the fundamental ideas of quantum information that form the basis for quantum cryptography, such as entanglement and quantifying quantum knowledge. We will introduce the security definition for quantum key distribution and see protocols and proofs of security for this task. We will also discuss the basics of device-independent quantum cryptography as well as other cryptographic tasks and protocols, such as bit commitment or position-based cryptography. Not offered 2025-26. Instructor: Staff.

CS/IDS 121. Relational Databases. *9 units (3-0-6); second term. Prerequisites: CS 1 or equivalent.* Introduction to the basic theory and usage of relational database systems. It covers the relational data model, relational algebra, and the Structured Query Language (SQL). The course introduces the basics of database schema design and covers the entity-relationship model, functional dependency analysis, and normal forms. Additional topics include other query languages based on the relational calculi, data-warehousing and dimensional analysis, writing and using stored procedures, working with hierarchies and graphs within relational databases, and an overview of transaction processing and query evaluation. Extensive hands-on work with SQL databases. Instructor: Ordentlich.

CS 124. Operating Systems. *12 units (3-6-3); third term. Prerequisites: CS 24.* This course explores the major themes and components of modern operating systems, such as kernel architectures, the process abstraction and process scheduling, system calls, concurrency within the OS, virtual memory management, and file systems. Students must work in groups to complete a series of challenging programming projects, implementing major components of an instructional operating system. Most programming is in C, although some IA32 assembly language programming is also necessary. Familiarity with the material in CS 24 is strongly advised before attempting this course. Not offered 2025-26. Instructor: Staff.

EE/CS/MedE 125. Digital Circuit Design with FPGAs and VHDL. *9 units (3-6-0);* For course description, see Electrical Engineering

EE/Ma/CS 126 ab. Information Theory. *9 units (3-0-6);* For course description, see Electrical Engineering

EE/Ma/CS/IDS 127. Error-Correcting Codes. *9 units (3-0-6);* For course description, see Electrical Engineering

CS 128. Interactive Theorem Proving. *9 units (3-0-6); second term. Prerequisites: CS 4 or instructor's permission.* This course introduces students to the modern practice of interactive tactic-based theorem proving using the Coq theorem prover. Topics will be drawn from logic, programming languages and the theory of computation. Topics will include: proof by induction, lists, higher-order functions, polymorphism, dependently-typed functional programming, constructive logic, the Curry-Howard correspondence, modeling imperative programs, and other topics if time permits. Students will be graded partially on attendance and will be expected to participate in proving theorems in class. Instructor: Vanier.

ME/CS/EE 129. Experimental Robotics. *9 units (1-7-1);* For course description, see Mechanical Engineering

CS 130. Software Engineering. *9 units (3-3-3); second term. Prerequisites: CS 2 and CS 18 (or equivalent).* This course presents a survey of software engineering principles relevant to all aspects of the software development lifecycle. Students will examine industry best practices in the areas of software specification, development, project management, testing, and release management, including a review of the relevant research literature. Assignments give students the opportunity to explore these topics in depth. Programming assignments use Python and Git, and students should be familiar with Python at a CS 1 level, and Git at a CS 2/CS 3 level, before taking the course. Instructor: Pinkston.

CS 131. Programming Languages. *9 units (3-0-6); third term. Prerequisites: CS 4.* CS 131 is a course on programming languages and their implementation. It teaches students how to program in a number of

simplified languages representing the major programming paradigms in use today (imperative, object-oriented, and functional). It will also teach students how to build and modify the implementations of these languages. Emphasis will not be on syntax or parsing but on the essential differences in these languages and their implementations. Both dynamically-typed and statically-typed languages will be implemented. Relevant theory will be covered as needed. Implementations will mostly be interpreters, but some features of compilers will be covered if time permits. Enrollment limited to 30 students. Instructor: Vanier.

CS 132. Web Development. *9 units (3-0-6); first term. Prerequisites: CS 1 or equivalent.* Covers full-stack web development with HTML5, CSS, client-side JS (ES6) and server-side JS (Node.js/Express) for web API development. Concepts including separation of concerns, the client-server relationship, user experience, accessibility, and security will also be emphasized throughout the course. Assignments will alternate between formal and semi-structured student-driven projects, providing students various opportunities to apply material to their individual interests. No prior web development background is required, though students who have prior experience may still benefit from learning best practices and HTML5/ES6 standards. Not offered 2025-26. Instructor: Staff.

ME/CS/EE 133 ab. Robotics. *9 units (3-2-4);* For course description, see Mechanical Engineering

ME/CS/EE 134. Robotic Systems. *9 units (1-7-1);* For course description, see Mechanical Engineering

EE/CS/EST 135. Power System Analysis. *9 units (3-3-3);* For course description, see Electrical Engineering

EE/Ma/CS/IDS 136. Information Measures and Applications. *9 units (3-0-6);* For course description, see Electrical Engineering

CS 137. Real-World Algorithm Implementation. *12 units (0-3-9); third term. Prerequisites: CS 24.* This course introduces algorithms in the context of their usage in the real world. The course covers compression, semi-numerical algorithms, RSA cryptography, parsing, and string matching. The goal of the course is for students to see how to use theoretical algorithms in real-world contexts, focusing both on correctness and the nitty-gritty details and optimizations. Students will choose to implement projects based on depth in an area or breadth to cover all the topics. Not offered 2025-26. Instructor: Blank.

CS 138. Computer Algorithms. *9 units (3-0-6); third term.* This course is identical to CS 38. Only graduate students for whom this is the first algorithms course are allowed to register for CS 138. See the CS 38 entry for prerequisites and course description. Instructors: Mahadev, Ralph.

CMS/CS/IDS 139. Analysis and Design of Algorithms. *12 units (3-0-9);* For course description, see Computing and Mathematical Sciences

CS 141. Hack Society: Projects from the Public Sector. *9 units (0-0-9); third term. Prerequisites: CS/IDS 142, 143, CMS/CS/EE/IDS 144, or permission from instructor.* There is a large gap between the public and private sectors' effective use of technology. This gap presents an opportunity for the development of innovative solutions to problems faced by society. Students will develop technology-based projects that address this gap. Course material will offer an introduction to the design, development, and analysis of digital technology with examples derived from services typically found in the public sector. Not offered 2025-26. Instructor: Ralph.

CS/EE/IDS 143. Networks: Algorithms & Architecture. *12 units (3-4-5); first term. Prerequisites: Ma 2, Ma 3, Ma/CS 6 a, and CS 38, or instructor permission.* Social networks, the web, and the internet are essential parts of our lives, and we depend on them every day. CS/EE/IDS 143 and CMS/CS/EE/IDS 144 study how they work and the "big" ideas behind our networked lives. In this course, the questions explored include: Why is an hourglass architecture crucial for the design of the Internet? Why doesn't the Internet collapse under congestion? How are cloud services so scalable? How do algorithms for wireless and wired networks differ? For all these questions and more, the course will provide a mixture of both mathematical analysis and hands-on labs. The course expects students to be comfortable with graph theory, probability, and basic programming. Instructor: Wierman.

CMS/CS/Ec/EE 144. Networks: Structure & Economics. *12 units (3-4-5);* For course description, see Computing and Mathematical Sciences

CS/EE 145. Projects in Networking. *9 units (0-0-9); third term. Prerequisites: Either CMS/CS/EE/IDS 144 or CS/IDS 142 in the preceding term, or instructor permission.* Students are expected to execute a substantial project in networking, write up a report describing their work, and make a presentation. Instructor: Wierman.

CS/EE 146. Control and Optimization of Networks. *9 units (3-3-3); second term. Prerequisites: Ma 2, Ma 3 or instructor's permission.* This course prepares senior undergraduates and beginning graduate students for research in networks, particularly energy networks. For 2025-26 academic year, it covers convex optimization theory, both smooth and nonsmooth optimization. It turns out that convexity is fundamental but smoothness (continuity, differentiability) is not, and this course explains how to extend directly the existence and characterization of optimal solutions to a nonsmooth setting. It then introduces a basic theory of stochastic optimization when problem parameters are uncertain, covering robust optimization, chance constrained optimization, scenario optimization, and two-stage optimization with recourse. These theories are applied to the optimal

power flow problem that underlies numerous power system applications. Familiarity with linear algebra and real analysis is required. Previous exposure to smooth convex optimization will be helpful but not necessary. Instructor: Low.

EE/CS 147. Digital Ventures Design. *9 units (3-3-3);* For course description, see Electrical Engineering

EE/CNS/CS 148 ab. Deep Learning. *12 units (3-0-9);* For course description, see Electrical Engineering

CS/Ec 149. Algorithmic Economics. *9 units (3-0-6); third term.* This course will equip students to engage with active research at the intersection of social and information sciences, including: algorithmic game theory and mechanism design; auctions; matching markets; and learning in games. Instructor: Niemeyer.

CS/IDS 150 ab. Probability and Algorithms. *9 units (3-0-6); first, third terms. Prerequisites: part a: CS 38 and Ma 5 abc; part b: part a or another introductory course in discrete probability.* Part a: The probabilistic method and randomized algorithms. Deviation bounds, k-wise independence, graph problems, identity testing, derandomization and parallelization, metric space embeddings, local lemma. Part b: Further topics such as weighted sampling, epsilon-biased sample spaces, advanced deviation inequalities, rapidly mixing Markov chains, analysis of boolean functions, expander graphs, and other gems in the design and analysis of probabilistic algorithms. Parts a & b are given in alternate years. Not offered 2025-26. Instructor: Schulman.

CS 151. Complexity Theory. *12 units (3-0-9); third term. Prerequisites: CS 21 and CS 38, or instructor's permission.* This course describes a diverse array of complexity classes that are used to classify problems according to the computational resources (such as time, space, randomness, or parallelism) required for their solution. The course examines problems whose fundamental nature is exposed by this framework, the known relationships between complexity classes, and the numerous open problems in the area. Not offered 2025-26. Instructor: Umans.

CS 152. Introduction to Cryptography. *12 units (3-0-9); first term. Prerequisites: Ma 1 b, CS 21, CS 38 or equivalent recommended.* This course is an introduction to the foundations of cryptography. The first part of the course introduces fundamental constructions in private-key cryptography, including one-way functions, pseudo-random generators and authentication, and in public-key cryptography, including trapdoor one-way functions, collision-resistant hash functions and digital signatures. The second part of the course covers selected topics such as interactive protocols and zero knowledge, the learning with errors problem and homomorphic encryption, and quantum cryptography: quantum money, quantum key distribution. The course is mostly theoretical and requires mathematical maturity. There will be a small

programming component. Not offered 2025-26. Instructor: Staff.

CS/IDS 153. Current Topics in Theoretical Computer Science. *9 units (3-0-6); third term. Prerequisites: CS 21 and CS 38, or instructor's permission.* May be repeated for credit, with permission of the instructor. Students in this course will study an area of current interest in theoretical computer science. The lectures will cover relevant background material at an advanced level and present results from selected recent papers within that year's chosen theme. Students will be expected to read and present a research paper. Instructors: Umans (section 1), Schulman (section 2).

CMS/CS/CNS/EE/IDS 155. Machine Learning & Data Mining. *12 units (3-3-6);* For course description, see Computing and Mathematical Sciences

CS/CNS/EE 156 ab. Learning Systems. *9 units (3-1-5); first, third terms. Prerequisites: Ma 2 and CS 2, or equivalent.* Introduction to the theory, algorithms, and applications of automated learning. How much information is needed to learn a task, how much computation is involved, and how it can be accomplished. Special emphasis will be given to unifying the different approaches to the subject coming from statistics, function approximation, optimization, pattern recognition, and neural networks. Instructor: Abu-Mostafa.

IDS/ACM/CS 157. Statistical Inference. *9 units (3-2-4);* For course description, see Information and Data Sciences

IDS/ACM/CS 158. Fundamentals of Statistical Learning. *9 units (3-3-3);* For course description, see Information and Data Sciences

CS/CNS/EE/IDS 159. Advanced Topics in Machine Learning. *9 units (3-0-6); third term. Prerequisites: CS 155; strong background in statistics, probability theory, algorithms, and linear algebra; background in optimization is a plus as well.* This course focuses on current topics in machine learning research. This is a paper reading course, and students are expected to understand material directly from research articles. Students are also expected to present in class, and to do a final project. Instructor: Yue.

EE/CS/IDS 160. Fundamentals of Information Transmission and Storage. *9 units (3-0-6);* For course description, see Electrical Engineering

EE/CS 161. Big Data Networks. *9 units (3-0-6);* For course description, see Electrical Engineering

CS/IDS 162. Data, Algorithms and Society. *9 units (3-0-6); second term. Prerequisites: CS 38 and CS 155 or 156 a.* This course examines algorithms and data practices in fields such as machine learning, privacy, and communication networks through a social lens. We will

draw upon theory and practices from art, media, computer science and technology studies to critically analyze algorithms and their implementations within society. The course includes projects, lectures, readings, and discussions. Students will learn mathematical formalisms, critical thinking and creative problem solving to connect algorithms to their practical implementations within social, cultural, economic, legal and political contexts. Enrollment by application. Taught concurrently with VC 72 and can only be taken once as CS/IDS 162 or VC 72. Instructors: Mushkin, Ralph.

CS 163. Projects in Machine Learning. *9 units (0-1-8); first. Prerequisites: CS 155 or equivalent.* This is a project-based course for students looking to gain practical experience in machine learning. Students are expected to be proficient in basic machine learning. Students will work in groups. Each group will be provided a project topic to work on along with domain expert advisors. Not offered 2025-26. Instructor: Bouman.

CS 164. Compilers. *9 units (3-0-6); first term. Prerequisites: CS 4 or instructor's permission. CS 24 and CS 131 are strongly recommended but not required. Limit 20 students.* This course covers the construction of compilers: programs which convert program source code to machine code which is directly executable on modern hardware. The course takes a bottom-up approach: a series of compilers will be built, all of which generate assembly code for x86 processors, with each compiler adding features. The final compiler will compile a full-fledged high-level programming language to assembly language. Topics covered include register allocation, conditionals, loops and dataflow analysis, garbage collection, lexical scoping, and type checking. This course is programming intensive. All compilers will be written in the OCaml programming language. Instructor: Vanier.

CS/CNS/EE/IDS 165. Foundations of Machine Learning and Statistical Inference. *12 units (3-3-6); second term. Prerequisites: CMS/ACM/EE 122, ACM/EE/IDS 116, CS 156 a, ACM/CS/IDS 157 or instructor's permission.* The course assumes students are comfortable with analysis, probability, statistics, and basic programming. This course will cover core concepts in machine learning and statistical inference. The ML concepts covered are spectral methods (matrices and tensors), non-convex optimization, probabilistic models, neural networks, representation theory, and generalization. In statistical inference, the topics covered are detection and estimation, sufficient statistics, Cramer-Rao bounds, Rao-Blackwell theory, variational inference, and multiple testing. In addition to covering the core concepts, the course encourages students to ask critical questions such as: How relevant is theory in the age of deep learning? What are the outstanding open problems? Assignments will include exploring failure modes of popular algorithms, in addition to traditional problem-solving type questions. Instructor: Anandkumar.

CS/EE/IDS 166. Computational Cameras. *12 units (3-3-6); third term. Prerequisites: ACM 104 or ACM 107 or equivalent.* Computational cameras overcome the limitations of traditional cameras, by moving part of the image formation process from hardware to software. In this course, we will study this emerging multi-disciplinary field at the intersection of signal processing, applied optics, computer graphics, and vision. At the start of the course, we will study modern image processing and image editing pipelines, including those encountered on DSLR cameras and mobile phones. Then we will study the physical and computational aspects of tasks such as coded photography, light-field imaging, astronomical imaging, medical imaging, and time-of-flight cameras. The course has a strong hands-on component, in the form of homework assignments and a final project. In the homework assignments, students will have the opportunity to implement many of the techniques covered in the class. Example homework assignments include building an end-to-end HDR (High Dynamic Range) imaging pipeline, implementing Poisson image editing, refocusing a light-field image, and making your own lensless "scotch-tape" camera. Instructor: Bouman.

EE/CS/IDS 167. Introduction to Data Compression and Storage. *9 units (3-0-6);* For course description, see Electrical Engineering

ME/CS/EE 169. Mobile Robots. *9 units (1-7-1);* For course description, see Mechanical Engineering

CS/CNS 171. Computer Graphics Laboratory. *12 units (3-6-3); first term. Prerequisites: Extensive programming experience and proficiency in linear algebra, such as Ma 1 b, Some knowledge of C++ programming.* This is a challenging course that introduces the basic ideas behind computer graphics and some of its fundamental algorithms. Topics include graphics input and output, the graphics pipeline, sampling and image manipulation, three-dimensional transformations and interactive modeling, basics of physically based modeling and animation, simple shading models and their hardware implementation, and some of the fundamental algorithms of scientific visualization. Students will be required to perform significant implementation. Instructor: Barr.

CS/IDS 172. Distributed Computing. *9 units (3-2-4); first term. Prerequisites: CS 24, CS 38.* Programming distributed systems. Mechanics for cooperation among concurrent agents. Programming sensor networks and cloud computing applications. Applications of machine learning and statistics by using parallel computers to aggregate and analyze data streams from sensors. Not offered 2025-26. Instructor: Staff.

CS/CNS 174. Computer Graphics Projects. *12 units (3-6-3); third term. Prerequisites: Extensive programming experience, CS/CNS 171 or instructor's permission.* This laboratory class offers students an opportunity for independent work including recent computer graphics research. In coordination with the instructor, students select a computer

graphics modeling, rendering, interaction, or related algorithm and implement it. Students are required to present their work in class and discuss the results of their implementation and possible improvements to the basic methods. May be repeated for credit with instructor's permission. Not offered 2025-26. Instructor: Staff.

EE/CS/MedE 175. Advanced Topics in Digital Design with FPGAs and VHDL. *9 units (3-6-0);* For course description, see Electrical Engineering

CS 176. Computer Graphics Research. *9 units (3-3-3); second term. Prerequisites: CS/CNS 171, or 173, or 174.* The course will go over recent research results in computer graphics, covering subjects from mesh processing (acquisition, compression, smoothing, parameterization, adaptive meshing), simulation for purposes of animation, rendering (both photo- and nonphotorealistic), geometric modeling primitives (image based, point based), and motion capture and editing. Other subjects may be treated as they appear in the recent literature. The goal of the course is to bring students up to the frontiers of computer graphics research and prepare them for their own research. Not offered 2025-26. Instructor: Staff.

CS/ACM 177 ab. Discrete Differential Geometry: Theory and Applications. *9 units (3-3-3); second term.* Working knowledge of multivariate calculus and linear algebra as well as fluency in some implementation language is expected. Subject matter covered: differential geometry of curves and surfaces, classical exterior calculus, discrete exterior calculus, sampling and reconstruction of differential forms, low dimensional algebraic and computational topology, Morse theory, Noether's theorem, Helmholtz-Hodge decomposition, structure preserving time integration, connections and their curvatures on complex line bundles. Applications include elastica and rods, surface parameterization, conformal surface deformations, computation of geodesics, tangent vector field design, connections, discrete thin shells, fluids, electromagnetism, and elasticity. Not offered 2025-26. Instructor: Staff.

CS/IDS 178. Numerical Algorithms and their Implementation. *9 units (3-3-3); third term. Prerequisites: CS 2.* This course gives students the understanding necessary to choose and implement basic numerical algorithms as needed in everyday programming practice. Concepts include: sources of numerical error, stability, convergence, ill-conditioning, and efficiency. Algorithms covered include solution of linear systems (direct and iterative methods), orthogonalization, SVD, interpolation and approximation, numerical integration, solution of ODEs and PDEs, transform methods (Fourier, Wavelet), and low rank approximation such as multipole expansions. Not offered 2025-26. Instructor: Staff.

CS 179. GPU Programming. *9 units (3-3-3); third term. Prerequisites: Good working knowledge of C/C++.* Some experience with computer graphics algorithms preferred. The use of Graphics Processing Units for

computer graphics rendering is well known, but their power for general parallel computation is only recently being explored. Parallel algorithms running on GPUs can often achieve up to 100x speedup over similar CPU algorithms. This course covers programming techniques for the Graphics processing unit, focusing on visualization and simulation of various systems. Labs will cover specific applications in graphics, mechanics, machine learning and signal processing. The course will use nVidia's parallel computing architecture, CUDA. Labwork requires extensive programming. Instructor: Barr.

CS 180. Master's Thesis Research. *Units (total of 45) are determined in accordance with work accomplished;* Instructor: Staff.

Bi/BE/CS 183. Introduction to Computational Biology and Bioinformatics. *9 units (3-0-6);* For course description, see Biology

CNS/Bi/EE/CS/NB 186. Vision: From Computational Theory to Neuronal Mechanisms. *12 units (4-4-4);* For course description, see Computation & Neural Systems

CNS/Bi/Ph/CS/NB 187. Neural Computation. *9 units (3-0-6);* For course description, see Computation & Neural Systems

BE/CS/CNS/Bi 191 ab. Biomolecular Computation. *9 units; part a (3-0-6) and part b (2-4-3);* For course description, see Bioengineering

BE/CS 196 ab. Design and Construction of Programmable Molecular Systems. *part a is 12 units (2-4-6) and part b is 9 units (2-4-3);* For course description, see Bioengineering

Ph/CS 219 abc. Quantum Computation. *9 units (3-0-6);* For course description, see Physics

CS 274 abc. Topics in Computer Graphics. *9 units (3-3-3); first, second, third terms. Prerequisites: instructor's permission.* Each term will focus on some topic in computer graphics, such as geometric modeling, rendering, animation, human-computer interaction, or mathematical foundations. The topics will vary from year to year. May be repeated for credit with instructor's permission. Not offered 2025-26. Instructor: Staff.

CS 280. Research in Computer Science. *Units in accordance with work accomplished;* Approval of student's research adviser and option adviser must be obtained before registering. Instructor: Staff.

CS 282 abc. Reading in Computer Science. *6 units or more by arrangement; first, second, third terms.* Instructor's permission required. Instructor: Staff.

CS 286 abc. Seminar in Computer Science. *3, 6, or 9 units, at the instructor's discretion;* Instructor's permission required. Instructor: Staff.

CS 287. Center for the Mathematics of Information Seminar. *3, 6, or 9 units, at the instructor's discretion; first, second, third terms.* Instructor's permission required. Not offered 2025-26. Instructor: Staff.

COMPUTING AND MATHEMATICAL SCIENCES

CMS 9. Introduction to research in Computing and Mathematical Sciences. *1 unit (1-0-0); first term.* This course will introduce students to research areas in CS through weekly overview talks by Caltech faculty and aimed at first-year undergraduates. More senior students may wish to take the course to gain an understanding of the scope of research in computing and mathematical sciences. Graded pass/fail. Instructor: Low.

CMS/ACM/IDS 107 ab. Linear Analysis with Applications. *12 units (3-0-9); first term, second term. Prerequisites: ACM/IDS 104 or equivalent, Ma 1b or equivalent.* Part a: Covers the basic algebraic, geometric, and topological properties of normed linear spaces, inner-product spaces and linear maps. Emphasis is placed both on rigorous mathematical development and on applications to control theory, data analysis and partial differential equations. Topics: Completeness, Banach spaces (l_p, L_p), Hilbert spaces (weighted l_2, L_2 spaces), introduction to Fourier transform, Fourier series and Sobolev spaces, Banach spaces of linear operators, duality and weak convergence, density, separability, completion, Schauder bases, continuous and compact embedding, compact operators, orthogonality, Lax-Milgram, Spectral Theorem and SVD for compact operators, integral operators, Jordan normal form. Part b: Continuation of ACM 107a, developing new material and providing further details on some topics already covered. Emphasis is placed both on rigorous mathematical development and on applications to control theory, data analysis and partial differential equations.Topics: Review of Banach spaces, Hilbert spaces, Linear Operators, and Duality, Hahn-Banach Theorem, Open Mapping and Closed Graph Theorem, Uniform Boundedness Principle, The Fourier transform (L1, L2, Schwartz space theory), Sobolev spaces (W^s,p, H^s), Sobolev embedding theorem, Trace theorem Spectral Theorem, Compact operators, Ascoli Arzela theorem, Contraction Mapping Principle, with applications to the Implicit Function Theorem and ODEs, Calculus of Variations (differential calculus, existence of extrema, Gamma-convergence, gradient flows) Applications to Inverse Problems (Tikhonov regularization, imaging applications). Instructors: Stuart, Hellmuth.

CMS/ACM 117. Probability Theory and Computational Mathematics. *12 units (3-0-9); first term. Prerequisites: ACM 104 and ACM 116; or instructor's permission.* This course offers a rigorous introduction to probability theory with applications to computational mathematics.

Emphasis is placed on nonasymptotic properties of probability models, rather than classical limit theorems. Topics include measure theory, integration, product measures, probability spaces, random variables and expectation, moments, Lp spaces, orthogonality, independence, concentration inequalities, distances between probability measures, the Berry-Esseen theorem, conditional expectation, and conditioning for Gaussian families. Instructor: Park.

CMS/ACM/EE 122. Mathematical Optimization. *12 units (4-0-8); first term. Prerequisites: linear algebra.* This class develops mathematical optimization from the perspective of certificates, duality, and convexity. Topics covered include Fenchel and Lagrange duality; representation of convex sets; linear and semidefinite programming; integer programming; convex relaxations for intractable problems; and numerical methods. Throughout the course, applications of optimization to problems arising in various areas of science and engineering are presented. Instructor: Chandrasekaran.

CMS/CS/IDS 139. Analysis and Design of Algorithms. *12 units (3-0-9); first term. Prerequisites: Ma 2, Ma 3, Ma/CS 6 a, CS 21, CS 38/138, and ACM/EE/IDS 116 or CMS/ACM/EE 122 or equivalent.* This course develops core principles for the analysis and design of algorithms. Basic material includes mathematical techniques for analyzing performance in terms of resources, such as time, space, and randomness. The course introduces the major paradigms for algorithm design, including greedy methods, divide-and-conquer, dynamic programming, linear and semidefinite programming, randomized algorithms, and online learning. Instructor: Schulman.

CMS/CS/Ec/EE 144. Networks: Structure & Economics. *12 units (3-4-5); second term. Prerequisites: Ma 2, Ma 3, Ma/CS 6 a, and CS 38, or instructor permission.* Social networks, the web, and the internet are essential parts of our lives, and we depend on them every day. CS/EE/IDS 143 and CMS/CS/EE/IDS 144 study how they work and the "big" ideas behind our networked lives. In this course, the questions explored include: What do networks actually look like (and why do they all look the same)?; How do search engines work?; Why do epidemics and memes spread the way they do?; How does web advertising work? For all these questions and more, the course will provide a mixture of both mathematical analysis and hands-on labs. The course expects students to be comfortable with graph theory, probability, and basic programming. Instructor: Mazumdar.

CMS/CS/CNS/EE/IDS 155. Machine Learning & Data Mining. *12 units (3-3-6); second term. Prerequisites: CS/CNS/EE 156 a. Having a sufficient background in algorithms, linear algebra, calculus, probability, and statistics, is highly recommended.* This course will cover popular methods in machine learning and data mining, with an emphasis on developing a working understanding of how to apply these methods in practice. The course will focus on basic foundational concepts underpinning and motivating modern machine learning and data mining

approaches. We will also discuss recent research developments. Instructor: Yue.

CMS 270. Advanced Topics in Computing and Mathematical Sciences. *Units by arrangement; second term.* Advanced topics that will vary according to student and instructor interest. May be repeated for credit. Not offered 2025-26. Instructor: Staff.

CMS 290 abc. Computing and Mathematical Sciences Colloquium. *1 unit; first, second, third terms. Prerequisites: Registration is limited to graduate students in the CMS department only.* This course is a research seminar course covering topics at the intersection of mathematics, computation, and their applications. Students are asked to attend one seminar per week (from any seminar series on campus) on topics related to computing and mathematical sciences. This course is a requirement for first-year PhD students in the CMS department. Instructor: Hoffmann.

CMS 300. Research in Computing and Mathematical Sciences. *Hours and units by arrangement;* Research in the field of computing and mathematical science. By arrangement with members of the staff, properly qualified graduate students are directed in research. Instructor: Staff.

CONTROL & DYNAMICAL SYSTEMS

CDS 90 abc. Senior Thesis in Control and Dynamical Systems. *9 units (0-0-9); first, second, third terms. Prerequisites: CDS 110 or CDS 112 (may be taken concurrently).* Research in control and dynamical systems, supervised by a Caltech faculty member. The topic selection is determined by the adviser and the student and is subject to approval by the CDS faculty. First and second terms: midterm progress report and oral presentation during finals week. Third term: completion of thesis and final presentation. Not offered on a pass/fail basis. Instructor: Ames.

CDS 110. Analysis and Design of Feedback Control Systems. *9 units (3-3-3); third term. Prerequisites: Ma 1 abc and Ma 2/102 or equivalents.* An introduction to analysis and design of feedback control systems in the time and frequency domain, with an emphasis on state space methods, robustness, and design tradeoffs. Linear input/output systems, including input/output response via convolution, reachability, and observability. State feedback methods, including eigenvalue placement, linear quadratic regulators, and model predictive control. Output feedback including estimators and two-degree of freedom design. Input/output modeling via transfer functions and frequency domain analysis of performance and robustness, including the use of Bode and Nyquist plots. Robustness, tradeoffs and fundamental limits, including the effects of external disturbances and unmodeled dynamics, sensitivity functions, and the Bode integral formula. Instructor: Mazumdar.

CDS 131. Linear Systems Theory. *12 units (3-0-9); second term. Prerequisites: Ma 1 b, Ma 2, ACM/IDS 104 or equivalent (may be taken concurrently).* Basic system concepts; state-space and I/O representation. Properties of linear systems, including stability, performance, robustness. Reachability, observability, minimality, state and output-feedback. Brief introduction to optimal control and control of networked and nonlinear systems. Motivating case studies from tech, biology, neuroscience, and medical systems. Instructor: Chung.

CDS 190. Independent Work in Control and Dynamical Systems. *Units to be arranged; first, second, third terms. Prerequisites: CDS 110.* Research project in control and dynamical systems, supervised by a CDS faculty member. Instructor: Staff.

CDS 212. Optimal Control and Reinforcement Learning. *9 units (3-0-6); third term. Prerequisites: CDS 110 (or equivalent) and CDS 131.* Advanced topics in optimization-based design of control, optimal control, and estimation/filtering. Optimal control theory using calculus of variations, Hamilton-Jacobi-Bellman equation, Pontryagin's maximum principle, and optimal control applications including reinforcement learning and model predictive control. Kalman filtering, Bayesian filtering, and nonlinear filtering methods for autonomous systems. Instructor: Chung.

CDS 231. Robust Control Theory. *9 units (3-2-4); third term. Prerequisites: CMS/ACM/IDS 107, CMS/ACM/EE 122, and CDS 131 (or equivalents).* Scalable analysis and synthesis of robust control systems. Motivation throughout from case studies in tech, neuro, bio, med, and socioeconomic networks. Co-design of sparse and limited (delayed, localized, quantized, saturating, noisy) sensing, communications, computing, and actuation using System Level Synthesis (SLS). Layering, localization, and distributed control. Computational scalability exploiting sparsity and structure. Uncertainty, including noise, disturbances, parametric uncertainty, unmodeled dynamics, and structured uncertainty (LTI/LTV). Tradeoffs, robustness versus efficiency, conservation laws and hard limits in time and frequency domain. Advanced topics, depending on class interest, can include interplay between automation, optimization, control, modeling and system identification, and machine learning, and nonlinear dynamics and sum of squares, global stability, regions of attraction. Instructor: Staff.

CDS 232. Nonlinear Dynamics. *9 units (3-0-6); second term. Prerequisites: CMS/ACM/IDS 107 or equivalent.* This course studies nonlinear dynamical systems beginning from first principles. Topics include: existence and uniqueness properties of solutions to nonlinear ODEs, stability of nonlinear systems from the perspective of Lyapunov, and behavior unique to nonlinear systems; for example: stability of periodic orbits, Poincare maps and stability/invariance of sets. The dynamics of robotic systems will be used as a motivating example. Instructor: Ames.

CDS 233. Nonlinear Control. *9 units (3-0-6); third term. Prerequisites: CDS 131 and CDS 232.* This course studies control synthesis for nonlinear control systems from Lyapunov perspective. Beginning with feedback linearization and the stabilization of feedback linearizable system, these concepts are related to control Lyapunov functions (CLF), and corresponding stabilization results in the context of optimization-based controllers. This leads to control barrier functions (CBFs), which enforce safety on nonlinear systems via safety filters. The interplay between stability (CLFs) and safety (CBFs) will be studied from a variety of perspectives. Advanced topics that build upon these core results will be discussed, including: robust, adaptive and event-triggered control, layered control architectures, model-predictive control and hybrid systems. The control of robotic systems will be used as a motivating example. Instructor: Ames.

ME/CDS/EE 234 ab. Advanced Robotics: Planning. *9 units (3-3-3);* For course description, see Mechanical Engineering

ME/CDS/EE 235 ab. Advanced Robotics: Kinematics. *9 units (3-3-3);* For course description, see Mechanical Engineering

CDS 242. Hybrid Systems: Dynamics and Control. *9 units (3-2-4); third term. Prerequisites: CDS 231 and CDS 232.* This class studies hybrid dynamical systems: systems that display both discrete and continuous dynamics. This includes topics on dynamic properties unique to hybrid system: stability types, hybrid periodic orbits, Zeno equilibria and behavior. Additionally, the nonlinear control of these systems will be considered in the context of feedback linearization and control Lyapunov functions. Applications to mechanical systems undergoing impacts will be considered, with a special emphasis on bipedal robotic walking. Not offered 2025-26. Instructor: Staff.

CDS 243. Adaptive Control. *4 units (2-0-2); third term. Prerequisites: CDS 231 and CDS 232.* Specification and design of control systems that operate in the presence of uncertainties and unforeseen events. Robust and optimal linear control methods, including LQR, LQG and LTR control. Design and analysis of model reference adaptive control (MRAC) for nonlinear uncertain dynamical systems with extensions to output feedback. Given in alternate years. Not offered 2025-26. Instructor: Staff.

CDS 244. System Identification. *4 units (2-0-2); third term. Prerequisites: CDS 231 and CDS 232.* Mathematical treatment of system identification methods for dynamical systems, with applications. Nonlinear dynamics and models for parameter identification. Gradient and least-squares estimators and variants. System identification with adaptive predictors and state observers. Parameter estimation in the presence of non-parametric uncertainties. Introduction to adaptive control. Not offered 2025-26. Instructor: Staff.

CDS 245. Data-driven Control. *9 units (3-0-6); second term. Prerequisites: CDS 131 and CDS 232.* Mathematical treatment of

data-driven machine learning methods for controlling robotic and dynamical systems with various uncertainties. Gradient and least-squares estimators and variants for dynamical systems for system identification and residual learning. Adaptive control methods for online adaptation and combination with deep learning. Learning-based control certificates such as neural Lyapunov functions and neural contraction metrics. Not offered 2025-26. Instructor: Staff.

Ae/CDS/ME 251 ab. Closed Loop Flow Control. *9 units (3-0-6 a, 1-6-1 b);* For course description, see Aerospace

CDS 270. Advanced Topics in Systems and Control. *Hours and units by arrangement; third term;* Topics dependent on class interests and instructor. May be repeated for credit. Not offered 2025-26. Instructor: Staff.

CDS 300 abc. Research in Control and Dynamical Systems. *Hours and units by arrangement;* Research in the field of control and dynamical systems. By arrangement with members of the staff, properly qualified graduate students are directed in research. Instructor: Staff.

ECONOMICS

Ec 11. Introduction to Economics. *9 units (3-2-4); first, second terms.* An introduction to economic methodology, models, and institutions. Includes both basic microeconomics and an introduction to modern approaches to macroeconomic issues. Students are required to participate in economics experiments. Instructors: Druckenmiller, Rangel.

Ec 97. Undergraduate Research. *Units to be arranged; any term. Prerequisites: Advanced economics and instructor's permission.* This course offers advanced undergraduates the opportunity to pursue research in Economics individually or in a small group. Graded pass/fail.

Ec 98 abc. Senior Research and Thesis. *; Prerequisites: instructor's permission.* Senior economics majors wishing to undertake research may elect a variable number of units, not to exceed 12 in any one term, for such work under the direction of a member of the economics faculty.

Ec 101. Selected Topics in Economics. *Units to be determined by arrangement with the instructor; offered by announcement.* Topics to be determined by instructor. Instructors: Staff, visiting lecturers.

Ec 105. Firms, Competition, and Industrial Organization. *9 units (3-0-6); third term. Prerequisites: Ec 11 or equivalent.* A study of how technology affects issues of market structure and how market structure affects observable economic outcomes, such as prices, profits, advertising, and research and development expenditures. Emphasis will

be on how the analytic tools developed in the course can be used to examine particular industries-especially those related to internet commerce-in detail. Each student is expected to write one substantial paper. Instructor: Xin.

Ec/Psy 106. Behavioral Game Theory. *9 units (3-0-6); first term. Prerequisites: PS/Ec 172.* In this course we will examine game theories that are explicitly meant to describe behavior of humans and other species. Prominent models are those with level-k hierarchies, quantal response equilibrium (QRE) and cursed equilibrium. Most of the data is experimental evidence from a wide variety of games. We will also learn about field evidence, mostly about mixed strategies and application of level-k hierarchies to firms' decisions. Data include biological measures such as response times, eye-tracking, fMRI and evidence from psychiatric disorders. Students are expected to replicate an existing experiment (individual students) or work in small teams to create and run a new experiment. Not offered 2025-26.

Ec/Psy 108. Foundations of Behavioral Economics. *9 units (3-0-6); third term.* In this course we will examine behavioral economics models in several key decision-making contexts: choice over time, choice under uncertainty, choice in market settings (i.e., buying and selling), and others. In each topic area we will begin by providing the standard neoclassical account for behavior, building from assumptions (axioms) to corresponding utility models. We will then ask whether critical axioms of neoclassical models are plausible by calling upon psychological insights and empirical data. Rejection of neoclassical axioms will lead to new models, behavioral economics models, in each setting. These models, mechanisms and their testable predictions will be discussed. Instructor: Sprenger.

Ec/Psy 109. Frontiers in Behavioral Economics. *9 units (3-0-6); first term. Prerequisites: Ec 11.* This course will study topics in behavioral economics demonstrating departures from the classic economics assumptions of rationality and pure self-interest. We will study evidence of these departures, models that have been designed to capture these preferences, and applications of these models to important economic questions. Topics will include biases and heuristics, risk preferences, self-control, strategic uncertainty, and social preferences, among others. The course will be based in readings from both classic and modern research. Methodologically, the course will combine both theoretical and empirical evidence of the mentioned above topics. Instructor: Nielsen.

Ec 110. Public Economics. *9 units (3-0-6); first term. Prerequisites: Ec 11.* The role of the government is multifold, from providing public goods to intervening in market failures. Additionally, some policies are motivated by paternalistic concerns of citizens not acting in their own best interest. Through a mix of theory, experiments, and empirical analysis, we will cover methods of assessing individual and societal welfare, the identification and measurement of consumer biases, and theories of when and how the government should intervene in the

economy. We will cover topics such as taxation, education, savings, and insurance, and the policies and nudges designed to implement these goals. Not offered 2025-26.

Ec/ACM/CS 112. Bayesian Statistics. *9 units (3-0-6); second term. Prerequisites: Ma 3, ACM/EE/IDS 116 or equivalent.* This course provides an introduction to Bayesian Statistics and its applications to data analysis in various fields. Topics include: discrete models, regression models, hierarchical models, model comparison, and MCMC methods. The course combines an introduction to basic theory with a hands-on emphasis on learning how to use these methods in practice so that students can apply them in their own work. Previous familiarity with frequentist statistics is useful but not required. Instructor: Rangel.

Ec 117. Matching Markets. *9 units (3-0-6); second term.* We will tackle the fundamental question of how to allocate resources and organize exchange in the absence of prices. Examples includes finding a partner, allocating students to schools, and matching donors to patients in the context of organ transplantations. While the main focus will be on formal models, we will also reason about the practical implications of the theory. Instructor: Caradonna.

BEM/Ec/ESE 119. Environmental Economics. *9 units (3-0-6);* For course description, see Business Economics & Management

BEM/Ec 120. Introduction to Sports Science. *9 units (3-0-6);* For course description, see Business Economics & Management

Ec 121 a. Theory of Value. *9 units (3-0-6); second term. Prerequisites: Ec 11 and Ma 1b (may be taken concurrently).* This course is the first half of the advanced course on General Equilibrium Theory, which is designed to equip students with a deep understanding of the core principles that govern economic systems at equilibrium. This first part delves into Consumer Choice Theory, where students will explore how individuals make consumption decisions based on their preferences, budget constraints, and the theory of utility maximization. Through a series of lectures and exercises, participants will learn to model consumer behavior and study how changes in market conditions affect consumer demand. Simultaneously, the course will cover Firm Theory, examining how firms make production and pricing decisions to maximize profits in competitive and non-competitive markets. Students will be introduced to the concepts of production functions, cost minimization, and profit maximization, alongside the analysis of market structures and their impact on firm behavior. This dual focus provides a comprehensive foundation for understanding the interactions between consumers and firms, setting the stage for more complex discussions on market equilibria, welfare economics, and policy implications in later parts of the course (Ec 121b). Through a blend of theoretical models and real-world applications, this course aims to develop critical thinking and analytical skills, preparing students for advanced studies in economics or careers that require a sophisticated understanding of how economies function at

equilibrium. Instructor: Saito.

Ec 121 b. Theory of Value. *9 units (3-0-6); third term. Prerequisites: Ec 11 and Ma 1b (may be taken concurrently). Ec 121a is highly recommended as background, but is not a prerequisite.* Building on the foundational knowledge acquired in the first part of the Advanced General Equilibrium course (Ec 121a), this second half of the course ventures into the study of Partial Equilibrium Analysis, Welfare Theorems, and Market Failures. Students will engage with Partial Equilibrium Analysis to understand the equilibrium conditions of specific markets in isolation, appreciating how changes in supply and demand in one market can impact prices and quantities without considering the economy-wide effects. This segment sets the groundwork for a deeper exploration of economic efficiency and resource allocation through a blend of theoretical insights and case studies. Then the course explores the First and Second Welfare Theorems, highlighting how, under ideal conditions, markets can achieve optimal social outcomes. The First Welfare Theorem shows that competitive markets lead to Pareto efficiency, where improving one's situation without harming another is impossible. The Second Theorem suggests that any Pareto efficient outcome can be reached through market equilibrium with correct resource distribution. However, real-world deviations such as monopolies, public goods, and externalities are examined to understand market failures and the potential for government intervention to enhance social welfare. This section equips students with the tools to evaluate economic policies, their efficiency, and their impact on society. Instructor: Saito.

Ec 122. Econometrics. *9 units (3-0-6); first term. Prerequisites: Ma 3.* The application of statistical techniques to the analysis of economic data. Instructor: Sherman.

Ec 123. Analysis of Consumer Choices. *9 units (3-0-6); second term. Prerequisites: Ec 122 is recommended but is not a prerequisite.* This course uses econometric tools to analyze choices made by people among a finite set of alternatives. Discrete choice models have been used to understand consumer behavior in many domains - shopping between brands (Toyota vs. BMW), where to go to college (Caltech or MIT), choosing between modes of transportation (car, metro, Uber, or bicycle), etc. Models studied include logit, nested logit, probit, and mixed logit, etc. Simulation techniques that allow estimation of otherwise intractable models will also be discussed. Not offered 2025-26.

Ec/PS 124. Identification Problems in the Social Sciences. *9 units (3-0-6); second term. Prerequisites: Ec 122.* Statistical inference in the social sciences is a difficult enterprise whereby we combine data and assumptions to draw conclusions about the world we live in. We then make decisions, for better or for worse, based on these conclusions. A simultaneously intoxicating and sobering thought! Strong assumptions about the data generating process can lead to strong but often less than credible (perhaps incredible?) conclusions about our world. Weaker

assumptions can lead to weaker but more credible conclusions. This course explores the range of inferences that are possible when we entertain a range of assumptions about how data is generated. We explore these ideas in the context of a number of applications of interest to social scientists. Instructor: Sherman.

Ec 125. Understanding Behavioral Heterogeneity. *9 units (3-0-6); third term. Prerequisites: permission of instructor.* This course will review existing data in several areas of controlled economic decision-making with a focus on individual and group differences. Theoretical and empirical approaches for understanding and decomposing heterogeneity into preference and stochastic components will be presented. Students will gain exposure to prominent experimental techniques, estimation of models of heterogeneity and heterogeneous treatment effects, and out-of-sample prediction exercises. Not offered 2025-26.

IDS/Ec/PS 126. Applied Data Analysis. *9 units (3-0-6);* For course description, see Information and Data Sciences

PS/Ec 128. Introduction to Public Health Economics and Policy. *9 units (3-0-6);* For course description, see Political Science

Ec 129. Economic History of the United States. *9 units (3-0-6); second term. Prerequisites: Ec 11.* An examination of certain analytical and quantitative tools and their application to American economic development. Each student is expected to write two substantial papers-drafts will be read by instructor and revised by students. Instructor: Janas.

Ec 130. Economic History of Europe from the Middle Ages to the Twentieth Century. *9 units (3-0-6); third term. Prerequisites: Ec 11.* Employs the theoretical and quantitative techniques of economics to help explore and explain the development of the European cultural area between 1000 and 1980. Topics include the rise of commerce, the demographic transition, the Industrial Revolution, and changes in inequality, international trade, social spending, property rights, and capital markets. Each student is expected to write nine weekly essays and a term paper. Not offered 2025-26.

BEM/Ec 131. International Trade and Finance. *9 units (3-0-6);* For course description, see Business Economics & Management

Ec 135. Economics of Uncertainty and Information. *9 units (3-0-6); first term. Prerequisites: Ec 11.* An analysis of the effects of uncertainty and information on economic decisions. Included among the topics are individual and group decision making under uncertainty, expected utility maximization, insurance, financial markets and speculation, product quality and advertisement, and the value of information. Instructor: Agranov.

Ec 136. Behavioral Decision Theory. *9 units (3-0-6); second term. Prerequisites: Ma 3.* This course is a course in decision theory that emphasizes axiomatic methods and mathematical analysis. It navigates not only through the traditional normative approach but also through more recent behavioral (i.e., descriptive) approaches to decision-making, incorporating psychological insights. We explore essential topics in decision theory such as dynamic choice, stochastic choice, ambiguity aversion, expected utility, and revealed preferences. This in-depth study provides students with a sophisticated understanding of the frameworks governing decision making, emphasizing the role of rigorous analysis and mentioning empirical evidence found in experimental economics and psychology. This course offers valuable insights into understanding individual behaviors across both economic and financial contexts as well as in broader scenarios, providing students with the mathematical proficiency required to analyze decision-making processes rigorously. Not offered 2025-26.

Ec 140. Economic Progress. *9 units (3-0-6); second term. Prerequisites: Ec 11; Ec 122 recommended.* This course examines the contemporary literature on economic growth and development from both a theoretical and historical/empirical perspective. Topics include a historical overview of economic progress and the lack thereof; simple capital accumulation models; equilibrium/ planning models of accumulation; endogenous growth models; empirical tests of convergence; the measurement and role of technological advancement; and the role of trade, institutions, property rights, human capital, and culture. Not offered 2025-26.

CMS/CS/Ec/EE 144. Networks: Structure & Economics. *12 units (3-4-5);* For course description, see Computing and Mathematical Sciences

CS/Ec 149. Algorithmic Economics. *9 units (3-0-6);* For course description, see Computer Science

PS/Ec 172. Game Theory. *9 units (3-0-6);* For course description, see Political Science

ESE/ME/EST/Ec/ChE/EE 179. Climate Change Impacts, Mitigation and Adaptation. *3 units (3-0-0);* For course description, see Environmental Science & Engineering

Ec 181 ab. Convex Analysis and Economic Theory. *9 units (3-0-6); third term. Prerequisites: Ma 1. Ec 121 a is recommended.* Introduction to the use of convex analysis in economic theory. Includes separating hyperplane theorems, continuity and differentiability properties of convex and concave functions, support functions, subdifferentials, Fenchel conjugates, saddlepoint theorem, theorems of the alternative, polyhedra, linear programming, and duality in graphs. Introduction to discrete convex analysis and matroids. Emphasis is on the finite-dimensional case, but infinite-dimensional spaces will be discussed. Applications to core convergence, cost and production functions, mathematical finance,

decision theory, incentive design, and game theory. Not offered 2025-26.

ELECTRICAL ENGINEERING

EE 1. The Science of Data, Signals, and Information. *9 units (3-0-6); third term.* Electrical Engineering has given rise to many key developments at the interface between the physical world and the information world. Fundamental ideas in data acquisition, sampling, signal representation, and quantification of information have their origin in electrical engineering. This course introduces these ideas and discusses signal representations, the interplay between time and frequency domains, difference equations and filtering, noise and denoising, data transmission over channels with limited capacity, signal quantization, feedback and neural networks, and how humans interpret data and information. Applications in various areas of science and engineering are covered. Satisfies the menu requirement of the Caltech core curriculum. Not offered 2025-26. Instructor: Vaidyanathan.

EE 2/102. Electrical Engineering Entrepreneurial and Research Seminar. *1 unit; second term.* Required for EE graduates and undergraduates. Weekly seminar given by successful entrepreneurs and EE faculty, broadly describing their path to success and introducing different areas of research in electrical engineering: circuits and VLSI, communications, control, devices, images and vision, information theory, learning and pattern recognition, MEMS and micromachining, networks, electromagnetics and opto-electronics, RF and microwave circuits and antennas, robotics and signal processing, specifically, research going on at Caltech and in the industry. Instructor: Yang.

EE/ME 7. Introduction to Mechatronics. *6 units (2-3-1); first term.* Mechatronics is the multi-disciplinary design of electro-mechanical systems. This course is intended to give the student a basic introduction to such systems. The course will focus on the implementations of sensor and actuator systems, the mechanical devices involved and the electrical circuits needed to interface with them. The class will consist of lectures and short labs where the student will be able to investigate the concepts discussed in lecture. Topics covered include motors, piezoelectric devices, light sensors, ultrasonic transducers, and navigational sensors such as accelerometers and gyroscopes. Graded pass/fail. Instructor: George.

APh/EE 9. Solid-State Electronics for Integrated Circuits. *6 units (2-2-2);* For course description, see Applied Physics

EE/CS 10 ab. Introduction to Digital Logic and Embedded Systems. *6 units (2-3-1); second, third terms.* This course is intended to give the student a basic understanding of the major hardware and software principles involved in the specification and design of embedded systems. The course will cover basic digital logic, programmable logic

devices, CPU and embedded system architecture, and embedded systems programming principles (interfacing to hardware, events, user interfaces, and multi-tasking). Instructor: George.

EE 13. Electronic System Prototyping. *3 units (0-3-0); first term.* This course is intended to introduce the student to the technologies and techniques used to fabricate electronic systems. The course will cover the skills needed to use standard CAD tools for circuit prototyping. This includes schematic capture and printed circuit board design. Additionally, soldering techniques will be covered for circuit fabrication as well as some basic debugging skills. Each student will construct a system from schematic to PCB to soldering the final prototype. Instructor: George.

APh/EE 23. Demonstration Lectures in Classical and Quantum Photonics. *9 units (3-0-6);* For course description, see Applied Physics

APh/EE 24. Introductory Optics and Photonics Laboratory. *9 units (1-3-5);* For course description, see Applied Physics

EE/APh 40. Physics of Electrical Engineering. *9 units (3-0-6); second term.* This course provides an introduction to the fundamental physics of modern device technologies in electrical engineering used for sensing, communications, computing, imaging, and displays. The course overviews topics including semiconductor physics, quantum mechanics, electromagnetics, and optics with emphasis on physical operation principles of devices. Example technologies include integrated circuits, optical and wireless communications, micromechanical systems, lasers, high-resolution displays, LED lighting, and imaging. Instructor: Marandi.

EE 44. Deterministic Analysis of Systems and Circuits. *12 units (4-0-8); first term. Prerequisites: Ph 1 abc, can be taken concurrently with Ma 2 and Ph 2 a.* Modeling of physical systems by conversion to mathematical abstractions with an emphasis on electrical systems. Introduction to deterministic methods of system analysis, including matrix representations, time-domain analysis using impulse and step responses, signal superposition and convolution, Heaviside operator solutions to systems of linear differential equations, transfer functions, Laplace and Fourier transforms. The course emphasizes examples from the electrical circuits (e.g., energy and data converters, wired and wireless communication channels, instrumentation, and sensing) , while providing some exposure to other selected applications of the deterministic analysis tool (e.g., public opinion, acoustic cancellation, financial markets, traffic, drug delivery, mechanical systems, news cycles, and heat exchange). Instructor: Hajimiri.

EE 45. Electronics Systems and Laboratory. *12 units (3-3-6); third term. Prerequisites: EE 44.* Fundamentals of electronic circuits and systems. Lectures on diodes, transistors, small-signal analysis, frequency- domain analysis, application of Laplace transform, gain stages, differential signaling, operational amplifiers, introduction to radio

and analog communication systems. Laboratory sessions on transient response, steady-state sinusoidal response and phasors, diodes, transistors, amplifiers. Instructor: Emami.

EE 55. Mathematics of Electrical Engineering. *12 units (4-0-8); first term. Prerequisites: Ma 1 abc.* Linear algebra and probability are fundamental to many areas of study in electrical engineering. This class provides the mathematical foundations of these topics with a view to their utility to electrical engineers. Topics include vector spaces, matrices and linear transformations, the singular value decomposition, elementary probability and random variables, common distributions that arise in electrical engineering, and data-fitting. Connections to signal processing, systems, communications, optimization, and machine learning are highlighted. Instructor: Kostina.

CS/EE/ME 75 abc. Multidisciplinary Systems Engineering. *3 units (2-0-1), 6 units (2-0-4), or 9 units (2-0-7) first term; 6 units (2-3-1), 9 units (2-6-1), or 12 units (2-9-1) second and third terms;* For course description, see Computer Science

EE 80 abc. Senior Thesis. *9 units; first, second, third terms. Prerequisites: instructor's permission, which should be obtained during the junior year to allow sufficient time for planning the research.* Individual research project, carried out under the supervision of a member of the electrical engineering faculty. Project must include significant design effort. A written thesis must be submitted to the department. Open only to senior electrical engineering majors. First term is offered pass/fail only, second and third terms are not offered on a pass/fail basis. Instructor: Staff.

EE 90. Analog Electronics Project Laboratory. *9 units (1-8-0); third term. Prerequisites: EE 45 or EE 85.* A structured laboratory course that gives the student the opportunity to design and build a simple analog electronics project. The goal is to gain familiarity with circuit design and construction, component selection, CAD support, and debugging techniques. Instructor: Russell.

EE 91 ab. Experimental Projects in Electronic Circuits. *9 units (1-8-0) first term; 6 units (1-5-0) second term; Prerequisites: EE 90; Recommended: EE/ME 007, EE/CS 10 ab, EE 13 and EE/MedE 114 ab (may be taken concurrently). Open to seniors; others only with instructor's permission.* An opportunity to do advanced original projects in analog or digital electronics and electronic circuits. Students select, design, and implement a significant electronics project and define the engineering approach using modern electronics techniques and demonstrate their design and finished product in two terms. DSP/microprocessor development support and analog/digital CAD facilities available. Instructor: Russell.

EE 99. Advanced Work in Electrical Engineering. *Units to be arranged;* Special problems relating to electrical engineering will be arranged. For

undergraduates; students should consult with their advisers. Graded pass/fail.

EE 105 ab. Electrical Engineering Seminar. *1 unit; first, third terms.* All candidates for the M.S. degree in electrical engineering are required to attend any graduate seminar in any division each week of each term. Graded pass/fail. Instructor: Yang.

ACM/EE 106 ab. Introductory Methods of Computational Mathematics. *12 units (3-0-9);* For course description, see Applied & Computational Math

APh/EE 109. Introduction to the Micro/Nanofabrication Lab. *9 units (0-6-3);* For course description, see Applied Physics

EE 110 abc. Embedded Systems Design Laboratory. *9 units; parts ab (3-4-2); part c (1-8-0); first, second, and third terms.* The student will design, build, and program a specified microprocessor-based embedded system. This structured laboratory is organized to familiarize the student with large-scale digital and embedded system design, electronic circuit construction techniques, modern development facilities, and embedded systems programming. The lectures cover topics in embedded system design such as display technologies, interfacing to analog signals, communication protocols, PCB design, and programming in high-level and assembly languages. Given in alternate years; offered 2025-26. . Instructor: George.

EE 111. Signal-Processing Systems and Transforms. *9 units (3-0-6); first term. Prerequisites: Ma 1.* An introduction to continuous and discrete time signals and systems with emphasis on digital signal processing systems. Study of the Fourier transform, Fourier series, z-transforms, and the fast Fourier transform as applied in electrical engineering. Sampling theorems for continuous to discrete-time conversion. Difference equations for digital signal processing systems, digital system realizations with block diagrams, analysis of transient and steady state responses, and connections to other areas in science and engineering. Instructor: Vaidyanathan.

EE 112. Introduction to Signal Processing from Data. *9 units (3-0-6); second term. Prerequisites: EE 111 or equivalent. Math 3 recommended.* Fundamentals of digital signal processing, extracting information from data by linear filtering, recursive and non-recursive filters, structural and flow graph representations for filters, data-adaptive filtering, multirate sampling, efficient data representations with filter banks, Nyquist and sub-Nyquist sampling, sensor array signal processing, estimating direction of arrival (DOA) information from noisy data, and spectrum estimation. Instructor: Vaidyanathan.

EE 113. Feedback and Control Circuits. *9 units (3-3-3); second term. Prerequisites: EE 45 (may be taken concurrently) or equivalent.* This class studies the design and implementation of feedback and control circuits.

The course begins with an introduction to basic feedback circuits, using both op amps and transistors. These circuits are used to study feedback principles, including circuit topologies, stability, and compensation. Following this, basic control techniques and circuits are studied, including PID (Proportional-Integrated-Derivative) control, digital control, and fuzzy control. There is a significant laboratory component to this course, in which the student will be expected to design, build, analyze, test, and measure the circuits and systems discussed in the lectures. Given in alternate years; not offered 2025-26. Instructor: George.

EE/MedE 114 ab. Analog Circuit Design. *12 units (4-0-8); second, third terms. Prerequisites: EE 44 or equivalent.* Analysis and design of analog circuits at the transistor level. Emphasis on design-oriented analysis, quantitative performance measures, and practical circuit limitations. Circuit performance evaluated by hand calculations and computer simulations. Recommended for juniors, seniors, and graduate students. Topics include: review of physics of bipolar and MOS transistors, low-frequency behavior of single-stage and multistage amplifiers, current sources, active loads, differential amplifiers, operational amplifiers, high-frequency circuit analysis using time- and transfer constants, high-frequency response of amplifiers, feedback in electronic circuits, stability of feedback amplifiers, and noise in electronic circuits, and supply and temperature independent biasing. A number of the following topics will be covered each year: trans-linear circuits, switched capacitor circuits, data conversion circuits (A/D and D/A), continuous-time Gm.C filters, phase locked loops, oscillators, and modulators. Not offered 2025-26. Instructor: Hajimiri.

EE/MedE 115. Micro-/Nano-scales Electro-Optics. *9 units (3-0-6); first term. Prerequisites: Introductory electromagnetic class and consent of the instructor.* The course will cover various electro-optical phenomena and devices in the micro-/nano-scales. We will discuss basic properties of light, imaging, aberrations, eyes, detectors, lasers, micro-optical components and systems, scalar diffraction theory, interference/interferometers, holography, dielectric/plasmonic waveguides, and various Raman techniques. Topics may vary. Not offered 2025-26.

ACM/EE/IDS 116. Introduction to Probability Models. *9 units (3-1-5);* For course description, see Applied & Computational Math

ME/EE/EST 117. Energy Technology and Policy. *9 units (3-0-6);* For course description, see Mechanical Engineering

Ph/APh/EE/BE 118 ab. Physics of Measurement. *9 units (3-0-6);* For course description, see Physics

Ph/APh/EE 118 c. Physics of Measurement: Moonbounce and Beyond - Microwave Scattering for Communications and Metrology. *9 units (3-0-6);* For course description, see Physics

EE/CS 119 abc. Advanced Digital Systems Design. *9 units (3-3-3) first, second term; 9 units (1-8-0) third term; first, second, third terms. Prerequisites: EE/CS 10 a or CS 24.* Advanced digital design as it applies to the design of systems using PLDs and ASICs (in particular, gate arrays and standard cells). The course covers both design and implementation details of various systems and logic device technologies. The emphasis is on the practical aspects of ASIC design, such as timing, testing, and fault grading. Topics include synchronous design, state machine design, arithmetic circuit design, application-specific parallel computer design, design for testability, CPLDs, FPGAs, VHDL, standard cells, timing analysis, fault vectors, and fault grading. Students are expected to design and implement both systems discussed in the class as well as self-proposed systems using a variety of technologies and tools. Given in alternate years; not offered 2025-26. Instructor: George.

EE/APh 120. Physical Optics. *9 units (3-0-6); first term. Prerequisites: Intermediate-level familiarity with Fourier transforms and linear systems analysis. Basic understanding of Maxwell's electromagnetic theory (EE/APh 40 and EE 44, or equivalent).* This course aims to provide a comprehensive introduction to optical phenomena, focusing on the central role of wave propagation. The course is divided into two parts. In the first part, we review geometrical optics before transitioning to the scalar theory of optical waves. Using linear system analysis and Fourier transforms, we study a range of topics, including diffraction, optical beams, resonators, and imaging systems. In the second part of the course, we explore the concepts of coherence and polarization and apply them to the study of a broader range of phenomena and systems where a full electromagnetic field description is necessary. This includes topics such as photonic crystals, meta-surfaces, and nonlinear optical processes. Instructor: Mirhosseini.

EE 121. Great Ideas in Data Science. *9 units (3-0-6); first term. Prerequisites: linear algebra and probability at the level of EE 55 or of ACM 104 + ACM 116.* Data science is a broad discipline that encompasses statistics, signal processing, machine learning, information theory, inverse problems, games, networks, and much else. This course provides a survey of some of the big ideas in these areas that have had significant conceptual and practical impact. Instructor: Chandrasekaran.

CMS/ACM/EE 122. Mathematical Optimization. *12 units (4-0-8);* For course description, see Computing and Mathematical Sciences

EE/APh 123. Advanced Lasers and Photonics Laboratory. *9 units (1-3-5); first term.* This course focuses on hands-on experience with advanced techniques related to lasers, optics, and photonics. Students have the opportunity to build and run several experiments and analyze data. Covered topics include laser-based microscopy, spectroscopy, nonlinear optics, quantum optics, ultrafast optics, adaptive optics, and integrated photonics. Limited enrollment. Not offered 2025-26. Instructor: Marandi.

EE/MedE 124. Mixed-mode Integrated Circuits. *9 units (3-0-6); second term. Prerequisites: EE 45 a or equivalent.* Introduction to selected topics in mixed-signal circuits and systems in highly scaled CMOS technologies. Design challenges and limitations in current and future technologies will be discussed through topics such as clocking (PLLs and DLLs), clock distribution networks, sampling circuits, high-speed transceivers, timing recovery techniques, equalization, monitor circuits, power delivery, and converters (A/D and D/A). A design project is an integral part of the course. Instructor: Emami.

EE/CS/MedE 125. Digital Circuit Design with FPGAs and VHDL. *9 units (3-6-0); third term. Prerequisites: EE/CS 10 or equivalent.* Study of programmable logic devices (FPGAs). Detailed study of the VHDL language, accompanied by tutorials of popular synthesis and simulation tools. Review of combinational circuits (both logic and arithmetic), followed by VHDL code for combinational circuits and corresponding FPGA-implemented designs. Review of sequential circuits, followed by VHDL code for sequential circuits and corresponding FPGA-implemented designs. Review of finite state machines, followed by VHDL code for state machines and corresponding FPGA-implemented designs. Final project. The course includes a wide selection of real-world projects, implemented and tested using FPGA boards. Not offered 2025-26. Instructor: Staff.

EE/Ma/CS 126 ab. Information Theory. *9 units (3-0-6); first, second terms. Prerequisites: Ma 3.* This class treats Shannon's mathematical theory of communication and the tools used to derive and understand it. The class is organized around fundamental questions and their solutions, leading to central results such as Shannon's source coding, channel coding, and rate-distortion theorems. Quantities that arise en route to these solutions include entropy, relative entropy, and mutual information for discrete and continuous random variables. The course explores the calculation of fundamental communication limits like entropy rate, capacity, and rate-distortion functions under a variety of source and communication channel models (e.g., memoryless, Markov, ergodic, and Gaussian). The course begins with a foundational discussion of the simplest communication scenarios and then expands to include topics like universal source coding, the role of side information in source coding and communications, and the generalization of earlier results to network systems. Network information theory topics include multiuser data compression and communication over multiple access channels, broadcast channels, and multiterminal networks. Philosophical and practical implications of the theory are also explored. This course, when combined with EE 112, EE/Ma/CS/IDS 127, EE/CS 161, and EE/CS/IDS 167, should prepare the student for research in information theory, coding theory, wireless communications, and/or data compression. Part b not offered 2025-26. Instructor: Effros.

EE/Ma/CS/IDS 127. Error-Correcting Codes. *9 units (3-0-6); third term. Prerequisites: EE 55 or equivalent.* This course develops from first principles the theory and practical implementation of the most important

techniques for combating errors in digital transmission and storage systems. Topics include highly symmetric linear codes, such as Hamming, Reed-Muller, and Polar codes; algebraic block codes, such as Reed-Solomon and BCH codes, including a self-contained introduction to the theory of finite fields; and low-density parity-check codes. Students will become acquainted with encoding and decoding algorithms, design principles and performance evaluation of codes. Instructor: Kostina.

EE 128 ab. Selected Topics in Digital Signal Processing. *9 units (3-0-6); second, third terms. Prerequisites: EE 111 and EE/CS/IDS 160 or equivalent required, and EE 112 or equivalent recommended.* The course focuses on several important topics that are basic to modern signal processing. Topics include multirate signal processing material such as decimation, interpolation, filter banks, polyphase filtering, advanced filtering structures and nonuniform sampling, optimal statistical signal processing material such as linear prediction and antenna array processing, and signal processing for communication including optimal transceivers. Not offered 2025-26.

ME/CS/EE 129. Experimental Robotics. *9 units (1-7-1);* For course description, see Mechanical Engineering

APh/EE 130. Electromagnetic Theory for Photonic Devices. *9 units (3-0-6);* For course description, see Applied Physics

APh/EE 131. Light Interaction with Atomic Systems-Lasers. *9 units (3-0-6);* For course description, see Applied Physics

APh/EE 132. Special Topics in Photonics and Optoelectronics. *9 units (3-0-6);* For course description, see Applied Physics

ME/CS/EE 133 ab. Robotics. *9 units (3-2-4);* For course description, see Mechanical Engineering

ME/CS/EE 134. Robotic Systems. *9 units (1-7-1);* For course description, see Mechanical Engineering

EE/CS/EST 135. Power System Analysis. *9 units (3-3-3); first term. Prerequisites: EE 44, Ma 2, or equivalent.* We are at the beginning of a historic transformation to decarbonize our energy system. This course introduces the basics of power systems analysis: phasor representation, 3-phase transmission system, transmission line models, transformer models, per-unit analysis, network matrix, power flow equations, power flow algorithms, optimal powerflow (OPF) problems, unbalanced power flow analysis and optimization,swing dynamics and stability. Instructor: Low.

EE/Ma/CS/IDS 136. Information Measures and Applications. *9 units (3-0-6); third term. Prerequisites: EE 55 or equivalent.* This class introduces information measures such as entropy, information

divergence, mutual information, information density, and establishes the fundamental importance of those measures in data compression, statistical inference, and error control. The course does not require a prior exposure to information theory; it is complementary to EE 126a. Not offered 2025-26. . Instructor: Kostina.

CS/EE/IDS 143. Networks: Algorithms & Architecture. *12 units (3-4-5);* For course description, see Computer Science

CMS/CS/Ec/EE 144. Networks: Structure & Economics. *12 units (3-4-5);* For course description, see Computing and Mathematical Sciences

CS/EE 145. Projects in Networking. *9 units (0-0-9);* For course description, see Computer Science

CS/EE 146. Control and Optimization of Networks. *9 units (3-3-3);* For course description, see Computer Science

EE/CS 147. Digital Ventures Design. *9 units (3-3-3); first term.* This course aims to offer the scientific foundations of analysis, design, development, and launching of innovative digital products and study elements of their success and failure. The course provides students with an opportunity to experience combined team-based design, engineering, and entrepreneurship. The lectures present a disciplined step-by-step approach to develop new ventures based on technological innovation in this space, and with invited speakers, cover topics such as market analysis, user/product interaction and design, core competency and competitive position, customer acquisition, business model design, unit economics and viability, and product planning. Throughout the term students will work within an interdisciplinary team of their peers to conceive an innovative digital product concept and produce a business plan and a working prototype. The course project culminates in a public presentation and a final report. Every year the course and projects focus on a particular emerging technology theme. Not offered 2025-26.

EE/CNS/CS 148 ab. Deep Learning. *12 units (3-0-9); second, third terms. Prerequisites: Undergraduate calculus, linear algebra, statistics, computer programming, machine learning. Experience programming in Python, (b only): Numpy and PyTorch.* Part a - Introduction to deep learning. Perceptrons, deep networks, convolutional neural networks, transformers. Optimization techniques: stochastic gradient descent, ADAM. Data wrangling: public datasets, sourcing datasets, crowdsourcing dataset annotation, dataset cleanup and curation. Performance evaluation and benchmarking. Training and inference using Numpy and PyTorch. Applications to computer vision, sound processing and natural language processing. The class will emphasize hands-on experience and good experimental practices. Part b - (Prerequisite: 148a or equivalent) The class will focus on large language models (LLMs) and language-and-vision models, as well as on generative methods for artificial intelligence (AI). Topics include deep neural

networks,transformers, large language models, generative adversarial networks, diffusion models, state-space models, and applications of such architectures and methods to image analysis, image synthesis, and text-to-image translation. Instructors: Perona, Gkioxari.

EE/APh 149. Frontiers of Nonlinear Photonics. *9 units (3-0-6); second term.* This course overviews recent advances in photonics with emphasis on devices and systems that utilize nonlinearities. A wide range of nonlinearities in the classical and quantum regimes is covered, including but not limited to second- and third-order nonlinear susceptibilities, Kerr, Raman, optomechanical, thermal, and multi-photon nonlinearities. A wide range of photonic platforms is also considered ranging from bulk to ultrafast and integrated photonics. The course includes an overview of the concepts as well as review and discussion of recent literature and advances in the field. Instructor: Marandi.

EE 150. Topics in Electrical Engineering. *Units to be arranged; terms to be arranged.* Content will vary from year to year, at a level suitable for advanced undergraduate or beginning graduate students. Topics will be chosen according to the interests of students and staff. Visiting faculty may present all or portions of this course from time to time. Instructor: Staff.

EE 151. Electromagnetic Engineering. *9 units (3-0-6); second term. Prerequisites: EE 45.* Foundations of circuit theory-electric fields, magnetic fields, transmission lines, and Maxwell's equations, with engineering applications. Instructor: Yang.

EE 152. High Frequency Systems Laboratory. *12 units (2-3-7); first term. Prerequisites: EE 45 or equivalent. EE 153 recommended.* The student will develop a strong, working knowledge of high-frequency systems covering RF and microwave frequencies. The essential building blocks of these systems will be studied along with the fundamental system concepts employed in their use. The first part of the course will focus on the design and measurement of core system building blocks; such as filters, amplifiers, mixers, and oscillators. Lectures will introduce key concepts followed by weekly laboratory sessions where the student will design and characterize these various system components. During the second part of the course, the student will develop their own high-frequency system, focused on a topic within remote sensing, communications, radar, or one within their own field of research. Not offered 2025-26. Instructor: Russell.

EE 153. Microwave Circuits and Antennas. *12 units (3-2-7); second term. Prerequisites: EE 45.* High-speed circuits for wireless communications, radar and broadcasting. Lectures on the theory of transmission lines, characteristic impedance, maximum power transfer, impedance matching, signal-flow graphs, power dividers, coupled lines, even and odd mode analyses, couplers, filters, noise, amplifiers, oscillators, mixers and antennas. Labs on the design, fabrication and measurement of microwave circuits such as microstrip filters, power

dividers, directional couplers, low-noise amplifiers and oscillators. Computer-Aided Design (CAD) software package: Microwave Office. Instructor: Antsos.

EE 154 ab. Practical Electronics for Space Applications. *9 units (2-3-4); second, third terms.* Part a: Subsystem Design: Students will be exposed to design for subsystem electronics in the space environment, including an understanding of the space environment, common approaches for low cost spacecraft, atmospheric / analogue testing, and discussions of risk. Emphasis on a practical exposure to early subsystem design for a TRL 3-4 effort. Part b: Subsystems to System Interfacing: Builds upon the first term by extending subsystems to be compatible with "spacecraft", including a near-space "flight" of prototype subsystems on a high-altitude balloon flight. Focus on qualification for the flight environment appropriate to a TRL 4-5 effort. Instructor: Klesh.

CMS/CS/CNS/EE/IDS 155. Machine Learning & Data Mining. *12 units (3-3-6);* For course description, see Computing and Mathematical Sciences

CS/CNS/EE 156 ab. Learning Systems. *9 units (3-1-5);* For course description, see Computer Science

EE/Ae 157 ab. Introduction to the Physics of Remote Sensing. *9 units (3-0-6); second, third terms. Prerequisites: Ph 2 or equivalent.* An overview of the physics behind space remote sensing instruments. Topics include the interaction of electromagnetic waves with natural surfaces, including scattering of microwaves, microwave and thermal emission from atmospheres and surfaces, and spectral reflection from natural surfaces and atmospheres in the near-infrared and visible regions of the spectrum. The class also discusses the design of modern space sensors and associated technology, including sensor design, new observation techniques, ongoing developments, and data interpretation. Examples of applications and instrumentation in geology, planetology, oceanography, astronomy, and atmospheric research. Part a offered spring term; Part b not offered 2025-26. Instructor: Rosen.

Ge/EE/ESE 157 c. Remote Sensing for Environmental and Geological Applications. *9 units (3-3-3);* For course description, see Geology

EE/APh 158. Quantum Electrical Circuits. *9 units (3-0-6); second term. Prerequisites: advanced-level familiarity with Maxwell's electromagnetic theory and quantum mechanics (EE 151 and Ph 125 abc, or equivalent).* This course focuses on superconducting electrical systems developed for quantum computing. The course begins with introductory topics in microwave engineering, quantum optics, and superconductivity, and proceeds to discuss superconducting linear circuits, Josephson-junction-based qubits, parametric couplers, and amplifiers. The course's final part focuses on systems for transferring quantum states remotely via propagating microwave and optical photons. Instructor: Mirhosseini.

CS/CNS/EE/IDS 159. Advanced Topics in Machine Learning. *9 units (3-0-6);* For course description, see Computer Science

EE/CS/IDS 160. Fundamentals of Information Transmission and Storage. *9 units (3-0-6); second term. Prerequisites: EE 55 or equivalent.* Basics of information theory: entropy, mutual information, source and channel coding theorems. Basics of coding theory: error-correcting codes for information transmission and storage, block codes, algebraic codes, sparse graph codes. Basics of digital communications: sampling, quantization, digital modulation, matched filters, equalization. Instructor: Hassibi.

EE/CS 161. Big Data Networks. *9 units (3-0-6); third term. Prerequisites: Linear Algebra ACM/IDS 104 and Introduction to Probability Models ACM/EE/IDS 116 or their equivalents.* Next generation networks will have tens of billions of nodes forming cyber-physical systems and the Internet of Things. A number of fundamental scientific and technological challenges must be overcome to deliver on this vision. This course will focus on (1) How to boost efficiency and reliability in large networks; the role of network coding, distributed storage, and distributed caching; (2) How to manage wireless access on a massive scale; modern random access and topology formation techniques; and (3) New vistas in big data networks, including distributed computing over networks and crowdsourcing. A selected subset of these problems, their mathematical underpinnings, state-of-the-art solutions, and challenges ahead will be covered. Not offered 2025-26.

EE 163. Communication Theory. *9 units (3-0-6); second term. Prerequisites: EE 111; ACM/EE/IDS 116 or equivalent.* Mathematical models of communication processes; signals and noise as random processes; sampling; modulation; spectral occupancy; intersymbol interference; synchronization; optimum demodulation and detection; signal-to-noise ratio and error probability in digital baseband and carrier communication systems; linear and adaptive equalization; maximum likelihood sequence estimation; multipath channels; parameter estimation; hypothesis testing; optical communication systems. Capacity measures; multiple antenna and multiple carrier communication systems; wireless networks; different generations of wireless systems. Not offered 2025-26.

EE 164. Stochastic and Adaptive Signal Processing. *9 units (3-0-6); second term. Prerequisites: ACM/EE/IDS 116 or equivalent.* Fundamentals of linear estimation theory are studied, with applications to stochastic and adaptive signal processing. Topics include deterministic and stochastic least-squares estimation, the innovations process, Wiener filtering and spectral factorization, state-space structure and Kalman filters, array and fast array algorithms, displacement structure and fast algorithms, robust estimation theory and LMS and RLS adaptive fields. Given in alternate years; not offered 2025-26. Instructor: Hassibi.

CS/CNS/EE/IDS 165. Foundations of Machine Learning and Statistical Inference. *12 units (3-3-6);* For course description, see Computer Science

CS/EE/IDS 166. Computational Cameras. *12 units (3-3-6);* For course description, see Computer Science

EE/CS/IDS 167. Introduction to Data Compression and Storage. *9 units (3-0-6); third term. Prerequisites: Ma 3 or ACM/EE/IDS 116.* The course will introduce the students to the basic principles and techniques of codes for data compression and storage. The students will master the basic algorithms used for lossless and lossy compression of digital and analog data and the major ideas behind coding for flash memories. Topics include the Huffman code, the arithmetic code, Lempel-Ziv dictionary techniques, scalar and vector quantizers, transform coding; codes for constrained storage systems. Given in alternate years; not offered 2025-26.

MedE/EE/BE 168 abc. Biomedical Optics: Principles and Imaging. *9 units (4-0-5) each;* For course description, see Medical Engineering

ME/CS/EE 169. Mobile Robots. *9 units (1-7-1);* For course description, see Mechanical Engineering

ACM/EE/IDS 170. Mathematics of Signal Processing. *12 units (3-0-9);* For course description, see Applied & Computational Math

EE/CS/MedE 175. Advanced Topics in Digital Design with FPGAs and VHDL. *9 units (3-6-0); third term. Prerequisites: EE/CS/MedE 125 or equivalent.* Quick review of the VHDL language and RTL concepts. Dealing with sophisticated, multi-dimensional data types in VHDL. Dealing with multiple time domains. Transfer of control versus data between clock domains. Clock division and multiplication. Using PLLs. Dealing with global versus local and synchronous versus asynchronous resets. How to measure maximum speed in FPGAs (for both registered and unregistered circuits). The (often) hard task of time closure. The subtleties of the time behavior in state machines (a major source of errors in large, complex designs). Introduction to simulation. Construction of VHDL testbenches for automated testing. Dealing with files in simulation. All designs are physically implemented using FPGA boards. Not offered 2025-26. Instructor: Staff.

ESE/ME/EST/Ec/ChE/EE 179. Climate Change Impacts, Mitigation and Adaptation. *3 units (3-0-0);* For course description, see Environmental Science & Engineering

EE/APh 180. Nanotechnology. *6 units (3-0-3); first term.* This course will explore the techniques and applications of nanofabrication and miniaturization of devices to the smallest scale. It will be focused on the understanding of the technology of miniaturization, its history and

present trends towards building devices and structures on the nanometer scale. Technology and instrumentation for nanofabrication as well as future trends will be described. Examples of applications of nanotechnology in the electronics, communications, data storage, sensing and biotechnology will be analyzed. Students will understand the underlying physics and technology, as well as limitations of miniaturization. Instructor: Scherer.

APh/EE 183. Physics of Semiconductors and Semiconductor Devices. *9 units (3-0-6);* For course description, see Applied Physics

EE/MedE 185. Micro/Nano Technology for Semiconductor and Medical Device. *9 units (3-0-6); second term. Prerequisites: APh/EE 9 or instructor's permission.* Micro/nano technology is indispensable for making advanced semiconductor devices. This course is designed to cover the state-of-the-art micro/nanotechnologies for the fabrication of VLSI/ULSI including BJT, CMOS, and BiCMOS. This course will emphasize fundamental science and technology used in modern semiconductor devices. Topics of technology will include cleaning, chemical etching, oxidation, diffusion, plasma etching, reactive ion etching (RIE), focused ion-beam (FIB) etching, thin-film deposition, metallization, advanced photolithography, etc. Not offered 2025-26. . Instructor: Tai.

CNS/Bi/EE/CS/NB 186. Vision: From Computational Theory to Neuronal Mechanisms. *12 units (4-4-4);* For course description, see Computation & Neural Systems

EE/MedE 187. MEMS/NEMS Technologies for Biomedical Devices. *9 units (3-0-6); second term. Prerequisites: APh/EE 9 or instructor's permission.* MEMS/NEMS technologies are useful to make advanced devices for such as electronics, optics, sensors, actuators and medicine. This course will emphasize the sciences and fundamentals of selected MEMS/NEMS technologies which enable micro 3D biomedical devices. For example, covered technologies include 3D wet isotropic/anisotropic chemical etching, bulk and surface micromachining (e.g., EDP, KOH and DRIE etching), wafer bonding, micro/nano molding and other advanced packaging techniques. This course covers many MEMS/NEMS devices but will emphasize their biomedical applications such as pressure sensors, microfluidics, accelerometers/gyros, lab-on-chips, micro total-analysis system, neuromodulation devices, biomedical implants, etc. Instructor: Tai.

EE 188. Computer Architecture. *9 units (3-3-3); third. Prerequisites: EE/CS 119a or EE/CS/MedE 125 or equivalent.* The course focuses on the design and implementation of modern CPUs and microcontrollers. The topics covered in addition to basic CPU architecture include caching and cache controllers, memory management and virtual memory, pipelining CPU operations, VLIW CPUs, branch prediction, and hardware multi-threading. The emphasis is on the practical aspects of CPU design such as timing, testing, and power use. There is significant laboratory

work in which the students are expected to design and implement the systems discussed in the class. Instructor: George.

BE/EE/MedE 189. Design and Construction of Biodevices. *12 units (3-6-3);* For course description, see Bioengineering

APh/EE 190 abc. Quantum Electronics. *9 units (3-0-6);* For course description, see Applied Physics

MedE/EE 204. Principles and Designs of Medical Neuromodulation Devices. *9 units (3-0-6);* For course description, see Medical Engineering

ME/CDS/EE 234 ab. Advanced Robotics: Planning. *9 units (3-3-3);* For course description, see Mechanical Engineering

ME/CDS/EE 235 ab. Advanced Robotics: Kinematics. *9 units (3-3-3);* For course description, see Mechanical Engineering

MedE/EE 268. Medical Imaging. *9 units (4-0-5);* For course description, see Medical Engineering

EE 291. Advanced Work in Electrical Engineering. *Units to be arranged;* Special problems relating to electrical engineering. Primarily for graduate students; students should consult with their advisers.

ENERGY SCIENCE AND TECHNOLOGY

ME/EE/EST 117. Energy Technology and Policy. *9 units (3-0-6);* For course description, see Mechanical Engineering

EE/CS/EST 135. Power System Analysis. *9 units (3-3-3);* For course description, see Electrical Engineering

ESE/ME/EST/Ec/ChE/EE 179. Climate Change Impacts, Mitigation and Adaptation. *3 units (3-0-0);* For course description, see Environmental Science & Engineering

ENGINEERING

E 2. Frontiers in Engineering and Applied Science. *1 unit; first term.* Open for credit to first-year students and sophomores. Weekly seminar by a member of the EAS faculty to discuss their area of engineering and group's research at an introductory level. The course can be used to learn more about different areas of study within engineering and applied science. Graded pass/fail. Instructor: Gold.

VC/E 81. Careers in STEAM. *1 unit (1-0-0);* For course description, see Visual Culture

E/VC 88. Critical Making. *9 units (3-0-6); third term.* This course examines the concepts and practices of maker culture through hands-on engagement, guest workshops, lectures, reading and discussions on the relations between technology, culture and society. Classes may include digital fabrication, physical computing, and other DIY technologies as well as traditional making. Major writings and practitioners' work may be covered from the study of maker culture, DIY culture, media, critical theory, histories of science, design and art. Not offered 2025-26.

E/H/VC 89. New Media Arts in the 20th and 21st Centuries. *9 units (3-0-6); second term.* This course will examine artists' work with new technology, fabrication methods and media from the late 19th Century to the present. Major artists, exhibitions, and writings of the period will be surveyed. While considering this historical and critical context, students will create their own original new media artworks using technologies and/or fabrication methods they choose. Possible approaches to projects may involve robotics, electronics, computer programming, computer graphics, mechanics and other technologies. Students will be responsible for designing and fabricating their own projects. Topics may include systems in art, the influence of industrialism, digital art, robotics, telematics, media in performance, interactive installation art, and technology in public space. Artists studied may include Eadweard Muybridge, Marcel Duchamp, Vladmir Tatlin, John Cage, Jean Tinguely, Stelarc, Survival Research Laboratories, Lynne Hershman Leeson, Edwardo Kac, Natalie Jeremenjenko, Heath Bunting, Janet Cardiff and others. Not offered 2025-26.

E 100. Special Topics in Engineering Applied Science. *Units to be arranged; terms to be arranged.* Content may vary from year to year, at a level suitable for advanced undergraduate or graduate students. Topics will be chosen to meet the emerging needs of students.

E/SEC 102. Scientific and Technology Entrepreneurship. *9 units (3-0-6); first term.* This course introduces students to the conceptual frameworks, the analytical approaches, the personal understanding and skills, and the actions required to launch a successful technology-based company. Specifically, it addresses the challenges of evaluating new technologies and original business ideas for commercialization, determining how best to implement those ideas in a startup venture, attracting the resources needed for a new venture (e.g., key people, corporate partners, and funding), organizing and operating a new enterprise, structuring and negotiating important business relationships, and leading early stage companies toward "launch velocity". Instructor: Low.

E/SEC 103. Management of Technology. *9 units (3-0-6); third term.* A course intended for students interested in learning how rapidly evolving technologies are harnessed to produce useful products or fertile new area for research. Students will work through Harvard Business School case studies, supplemented by lectures to elucidate the key issues.

There will be a term project where students predict the future evolution of an exciting technology. The course is team-based and designed for students considering choosing an exciting research area, working in companies (any size, including start-ups) or eventually going to business school. Topics include technology as a growth agent, financial fundamentals, integration into other business processes, product development pipeline and portfolio management, learning curves, risk assessment, technology trend methodologies (scenarios, projections), motivation, rewards and recognition. Industries considered will include electronics (hardware and software), aerospace, medical, biotech, etc. Students will perform both primary and secondary research and through analysis present defensible projections. E/SEC 102 and E/ME/MedE 105 are useful but not required precursors.

E/ME/MedE 106 ab. Design for Freedom from Disability. *9 units (3-0-6); terms to be arranged.* This Product Design class focuses on people with Disabilities and is done in collaboration with Rancho Los Amigos National Rehabilitation Center. Students visit the Center to define products based upon actual stated and observed needs. Designs and testing are done in collaboration with Rancho associates. Speakers include people with assistive needs, therapists and researchers. Classes teach normative design methodologies as adapted for this special area. Not offered 2025-26.

E 110. Principles of University Teaching and Learning in STEM. *3 units (2-0-1); second, third terms.* This graduate course examines the research on university-level STEM (science, technology, engineering, and mathematics) teaching and learning, which has been used to inform a well-established body of evidence-based teaching practices. Weekly interactive meetings will provide focused overviews and guided application of key pedagogical research, such as prior knowledge and misconceptions, novice-expert differences, and cognitive development as applied to university teaching. We will explore the roles of active learning, student engagement, and inclusive teaching practices in designing classes where all students have an equal opportunity to be successful and feel a sense of belonging, both in the course and as scientists. Readings will inform in-class work and students will apply principles to a project of their choice. Instructors: Horii, Weaver.

ENGLISH

Hum/En 21. Monsters and Marvels. *9 units (3-0-6);* For course description, see Humanities

Hum/En 22. Inequality. *9 units (3-0-6);* For course description, see Humanities

Hum/En 23. Literature and Medicine. *9 units (3-0-6);* For course description, see Humanities

Hum/En 24. The Scientific Imagination in English Literature. *9 units (3-0-6);* For course description, see Humanities

Hum/En 25. The Human Animal. *9 units (3-0-6);* For course description, see Humanities

Hum/En 26. What Is Imagination?. *9 units (3-0-6);* For course description, see Humanities

Hum/En 27. Introduction to the Modern Novel. *9 units (3-0-6);* For course description, see Humanities

Hum/En 28. Telling Time in American Modernism. *9 units (3-0-6);* For course description, see Humanities

Hum/En 29. Dream Narratives. *9 units (3-0-6);* For course description, see Humanities

Hum/En 30. Reading Animals. *9 units (3-0-6);* For course description, see Humanities

Hum/En 31. Introduction to Black Literature and Culture in the United States. *9 units (3-0-6);* For course description, see Humanities

Hum/En 32. The Origins of Science Fiction: Fictions about Science. *9 units (3-0-6);* For course description, see Humanities

Hum/En 33. Modern Metamorphoses. *9 units (3-0-6);* For course description, see Humanities

Hum/En 34. Literature and Deception. *9 units (3-0-6);* For course description, see Humanities

Hum/En 35. Masterworks of Contemporary Latin American Fiction. *9 units (3-0-6);* For course description, see Humanities

Hum/En 36. American Literature and Culture. *9 units (3-0-6);* For course description, see Humanities

Hum/En 37. Welcome to Dystopia. *9 units (3-0-6);* For course description, see Humanities

Hum/En 39. The Ethics of Friendship. *9 units (3-0-6);* For course description, see Humanities

Hum/En 42. Climate Fiction. *9 units (3-0-6);* For course description, see Humanities

Hum/En 43. Nature Writing. *9 units (3-0-6);* For course description, see Humanities

Hum/En 46. Race and Labor in Modern American Literature. *9 units (3-0-6);* For course description, see Humanities

Hum/En 54. Introduction to English Renaissance Poetry. *9 units (3-0-6);* For course description, see Humanities

Hum/En 56. Special Topics in Humanities/English. *Units are by arrangement;* For course description, see Humanities

En/Wr 83. Personal Narrative and STEM Research. *9 units (3-0-6); third term.* This course focuses on personal narrative and memoir writing by STEM researchers. STEM research strives for objectivity and replicability, and key genres of STEM research writing require that writers repress their subjectivity and individuality. However, a researcher's experience of inquiry is often deeply personal and emotional, and some researchers choose to write about those experiences in personal essays and memoirs. We will analyze a wide variety of this narrative writing, and we will examine connections between the narratives' formal features and the rhetorical effects they might have on readers. Drawing on what we learn, students will compose an excerpt of their own memoir or a stand-alone personal narrative essay. The course will also explore current approaches to spoken storytelling sometimes utilized by researchers, such as the Moth story and the TED talk. Satisfies the Institute scientific writing requirement and oral communications requirements for students in all options. Instructor: Hall.

En/Wr 84. Communicating Science to Non-Experts. *9 units (3-0-6); third term.* This course offers instruction in writing and speaking about science and technology for non-expert audiences. Instruction focuses on how to convey complex technical information in clear, engaging prose and speech in a variety of contexts. Readings in different genres (e.g., the newspaper discovery story, the op-ed, the personal narrative, the explainer talk) raise issues for discussion and serve as models for assignments in these genres. The workshop-style nature of this course relies on drafting and revision in response to peer and instructor feedback. Satisfies the Institute scientific writing requirement and the option oral communications requirement for humanities majors. Not offered 2025-26.

En 85. Poetry Writing. *9 units (3-0-6); second term.* When William Blake wrote "to see a World in a Grain of Sand," he tapped into poetry's power to model the universe. For instance, once we set up a simile between "world" and "grain of sand", we can test this hypothesis of sameness. How is sand like the world? Where will the model fail? And what might that tell us? Imagery, sensory language, arguments, ideas, and verse form itself can lead poetry toward power and discovery. This pursuit can reach from the page into one's own life. We will work hard together on poems, our own and one another's. With permission of the instructor students may repeat the course for credit. Instructor: Factor.

En 86. Fiction Writing. *9 units (3-0-6); second term.* The class is conducted as a workshop of fiction writing. Contemporary short stories and novel excerpts are discussed, as well as the art and craft of writing well. The course covers the essential elements of fiction writing, including character, voice, setting, world building, scene, summary, plot, and dialogue. Each week, we discuss a particular craft element, analyze published fiction, and provide feedback on student writing. Near the end of the course, students critique the work of their peers in small-group workshops. Instructor: Lepucki.

En 87. Creative Nonfiction. *9 units (3-0-6); first term.* This class is a seminar about the reading and writing of creative nonfiction. Contemporary personal essays, profiles of public figures, and other examples of this vibrant form will be read and discussed, as well as the art and craft of writing well. The course covers the essential elements of the genre such as characterization, dramatization, voice, and the ethics of writing about real life. Each week, we will analyze published nonfiction and practice writing with in-class prompts; out of class, students will complete short exercises for feedback. Near the end of the course, students will turn in one long piece of creative nonfiction (10-15 pages) to showcase what they've learned. Instructor: Lepucki.

En 89. Journalism and Storytelling. *9 units (3-0-6); third term.* Today's political and social turmoil have cast a sometimes harsh light on news media and the journalistic writing approach. Is the media fulfilling its role in our democracy? What should it be? And what approach should journalists take in their reporting and writing? This course will ponder these questions as it explores how to construct interesting, relevant, journalistic storytelling, including the use of new media tools. It will emphasize the foundations of the craft, such as close attention to fact, accuracy, clarity and precision, and examine its critical components, such as story form, reporting and interviewing, theme and scene, and character development. It will offer opportunities to construct a long-form journalistic piece. Students will produce numerous stories and other writing during the class, including profiles, issues, analysis and reviews. Several of these will be offered for publication in The California Tech. There will be class visits by professional journalists and a possible off-campus excursion. Not offered 2025-26.

En 98. Reading in English. *9 units (1-0-8); Prerequisites: instructor's permission.* An individual program of directed reading in English or American literature, in areas not covered by regular courses. En 98 is intended primarily for English majors and minors. Interested students should confer with an English faculty member and agree upon a topic before registering for the course. Instructor: Staff.

En 99 ab. Senior Tutorial for English Majors. *9 units (1-0-8);* Students will study research methods and write a research paper. Required of students in the English option.

En 100. Artificial Life: Literary Automata. *9 units (3-0-6); second term.* Well before the advent of the Machine Age, literary texts have been populated by various kinds of ingenious automata, often in animal or human form. This course surveys the role of the automaton in literary texts in order to consider how the notion of "artificial life" changes over time, with a focus on the special case of the human machine. Readings from the eighteenth and nineteenth centuries to include texts by la Mettrie, Hoffmann, Kleist, Shelley, Poe, and de l'Isle-Adam. We will conclude with a classic text from the twentieth century: Isaac Asimov's *I, Robot.*. Instructor: Holland.

En 101. Recalling the Wild. *9 units (3-0-6); second term.* City-dwellers invented the concept of wilderness, as a space apart from human laws and culture. This course takes a critical look at the different values attributed to that space as it has been colonized by the human imagination. Our discussions will focus on the emergence of the perception of wilderness in European literature in the eighteenth and nineteenth centuries, but we conclude with the question: what meaning do we invest the concept of "wilderness" with today? Readings will include works by Buffon, Toqueville, Chateaubriand, Byron, Thoreau, Wells, and London. Not offered 2025-26.

En 103. Introduction to Medieval British Literature. *9 units (3-0-6); first term.* This course offers a tour of major (as well as some minor) genres and works written in Britain prior to 1500. Far from a literary "dark age," the Middle Ages fostered dramatic experiments in narrative form, bequeathing to modern literature some of its best-loved genres and texts. We will practice reading in Middle English-the language of Chaucer and his contemporaries-while we concentrate on the following questions: how did these texts circulate among readers? How do they establish their authority? What kinds of historical and cultural currents to they engage? Texts may include the lives of saints, the confessions of sinners, drama, lyrics, romances, selections from Chaucer's Canterbury Tales, and Malory's Morte Darthur. Readings will be in Middle and modern English. Not offered 2025-26.

En 106. Poetry and the Project of Justice. *9 units (3-0-6); third term.* This course explores how contemporary poets grapple with the most urgent questions of our moment: identity, equality, environmental crisis, and justice. In this class, students will gain confidence in reading, discussing, and writing about contemporary poems and will encounter recent and more distant traditions of protest poetry. We will ask how poetic language articulates questions of embodiment, community, law, and memory. The syllabus will focus in particular on writers of color, including queer and indigenous poets, and will include opportunities to attend local poetry readings. Not offered 2025-26.

En 107. Medieval Romance. *9 units (3-0-6); third term.* The medieval term romanz designated both a language, French, and a genre, romance, dedicated to the adventures of knights and ladies and the villains, monsters, magic, and miles that stood in their way. This course

explores key examples from the twelfth through the fifteenth centuries, while also examining evolutions in the form. We will consider how romances figured love and desire as well as negotiated questions of law, territory, and cultural difference. Authors and texts may include Chretien de Troyes, Marie de France, Gawain and the Green Knight, Arthurian legends, outlaw tales, and hagiography. Not offered 2025-26.

En 109. Madness and Reason. *9 units (3-0-6); second term.* Madness threatens to dissolve boundaries of the most various kinds: between the human and the inhumane, reality and fantasy, sickness and health. One of the tasks of a literary text is to subdue and contain madness through the construction of rational frameworks. How does a literary text accomplish this? Which strategies, such as the use of irony and humor, are the most effective? What role do insane characters play in literary texts? And when - if ever - should we consider an excess of reason as a kind of madness in its own right? Selected readings from Shakespeare, Voltaire, Goethe, Hoffmann, Büchner, Gogol, and Schnitzler, among others. Not offered 2025-26.

En/VC 110. Sinners, Saints, and Sexuality in Premodern Literature. *9 units (3-0-6); first term.* This class explores the history of sexuality and gender across the Middle Ages and Renaissance. Exploring both literary texts and visual representation, it considers how previous eras and cultures understood embodiment, sexuality, and gender and asks how we, as modern readers and viewers, approach these questions across the distance of centuries. We will read across a wide range of literature, including theology, philosophy, fiction, romance, and spiritual biography, and examine manuscript illustrations and other early visual media. Questions we will take up include the following: how did writers and artists construct the "naturalness" or "unnaturalness" of particular bodies and bodily acts? How did individuals understand the relationship between their own bodies and those of others? In what ways did writing and art authorize, scrutinize, or otherwise parse the boundaries of the licit and illicit? Finally, how have modern critics framed these questions? How do we approach and make use of earlier theories of sex and gender? Not offered 2025-26.

En 112. Nineteenth-Century American Poetry. *9 units (3-0-6); third term.* In the 1855 edition of Leaves of Grass, Walt Whitman claimed that "the United States themselves are essentially the greatest poem." We might ask any number of questions in response to Whitman. If the United States are a poem, then who wrote it? What is this poem about? What genre is it? Is anyone reading it? Is it actually any good? Though we might approach Whitman's statement with some apprehension from our historical moment, this course will take seriously American life lived within poetry and the lives poems lived across the country. Together, we will track the development of American poetry as it engages with enslavement, abolition, genocide, war, beauty, nature, racialization, constructions of gender, sexuality, and affect. Ultimately, we will ask what reading nineteenth-century American poetry, or nineteenth-century America as a poem, might mean for our understanding of the country

today. Readings may include Bryant, Poe, Longfellow, Schoolcraft (Bamewawagezhikaquay), Whitman, Dickinson, Harper, Dunbar, and Noguchi. Not offered 2025-26.

En 115. The Women of Ancient Epic. *9 units (3-0-6); second term.* Epic remains the most ancient and most modern of literary genres. Women in ancient epic begin as prizes of honor for male warriors and become powerful witches and queens, while some contemporary women writers allow their ancient heroines to speak in their own voices. From Homer to the present, epic narratives also traverse continents as they narrate the founding and foundering of empires historical and imaginary. This course introduces students to key classical epics while exploring historical and contemporary adaptations from Dante's *Divine Comedy* to Madeline Miller's *Circe* . By examining the afterlives of epic, we will consider how the genre changes when taken up by the gender typically marginalized in the classical tradition. Possible authors include Homer, Apollonius of Rhodes, Virgil, Ovid, Dante, Christa Wolf, Ursula K. Le Guin, Madeline Miller, and María Baranda. Not offered 2025-26.

En/VC 116. Picturing the Universe. *9 units (3-0-6); third term. Prerequisites: Students are required to take two First-Year Humanities classes before enrolling in Advanced Humanities.* Whether you are a physicist, photographer, or bibliophile, grab a warm jacket. The night sky beckons. We will study 19th-century literary, artistic, and scientific responses to new understandings of the universe as dynamic, decentered, and limitless. In Victorian England, picturing the universe in literature and recording celestial light in photographs defied the physiological limitations of human observation and fueled larger debates about objective evidence and subjective documentation. We will examine how these historic contexts continue to shape how we picture the universe in the 21st-century. Instructor: Sullivan.

En/VC 117. The New York School of Poets. *9 units (3-0-6); second term.* Starting in the early 1950s, the New York School of poets challenged the stuffy orthodoxy of mid-century American poetry by adopting the experimental tactics of European avant-garde movements such as Dadaism and Surrealism. This course offers a critical exploration of this influential group's varied body of work, with special attention to its extensive connections to the visual arts. Throughout the course, we will think about the New York School's activities in the context of Cold War American culture, emergent forms of queer sociality, and the rapidly changing urban environment of postwar Manhattan. Writers and artists covered may include Frank O'Hara, John Ashbery, Amiri Baraka, Kenneth Koch, Barbara Guest, James Schuyler, Joe Brainard, Alice Notley, Ted Berrigan, and Eileen Myles. Instructor: Schneiderman.

En 118. Classical Mythology. *9 units (3-0-6); third term.* Why did the Greeks and Romans remain fascinated with the same stories of gods and heroes for more than a thousand years? On the other hand, how did they adapt old stories to fit new times and places? Our aim is to explore the history of classical poetry as a history of reading even older classical

poetry. The course is also an excellent introduction to ancient literature in general. Readings might include Homer's 'Odyssey,' Aeschylus, Sophocles, Euripides, Ovid, and Seneca. Instructor: Haugen.

En 119. Displacement. *9 units (3-0-6); third term.* This class combines the theme of geographic change, including migration and immigration, with two literary questions. Why do novels of migration so often focus on a strongly marked central character? And why is that character so often lonely or isolated? Past readings have included Chinua Achebe's 'Things Fall Apart' (1959), Ottessa Moshfegh's 'My Year of Rest and Relaxation' (2018), and Charles Yu's 'Interior Chinatown' (2020). Those familiar with these novels will notice that, in our class, migration may mean international uprooting or some other profound change closer to home. Not offered 2025-26. .

En 120. What Women Want: Desire and the Modern American Novel. *9 units (3-0-6); second term.* The question of what a woman wants animates a central strain of the modern American novel, as do evolving ideas about what women can and cannot have. This course considers female desire-for personal agency and freedom, self- and sexual fulfillment, economic and social opportunity-across a half dozen novels written from about 1880 - 1940, in light of some of the cultural forces that shape and constrain characters' (and real women's) horizons. Authors covered may include Henry James, Edith Wharton, Theodore Dreiser, Anzia Yezierska, Nella Larsen, and Zora Neale Hurston. Not offered 2025-26.

En 121. Early Novels. *9 units (3-0-6); second term.* Before modern media, novels had to stand in for every type of sequential entertainment: television, movies, and even hyperlinked web pages. The stories we read in this class, dating from ancient Greece to the 1600s, are long, florid, fantastic, and crammed with characters. What do these books reveal about the values and interests of people in the past? Readings may include Heliodorus, Lodovico Ariosto, and John Bunyan. Not offered 2025-26.

En 123. The 19th-Century English Novel. *9 units (3-0-6); third term.* A survey of the 19th-century novel from Austen through Conrad, with special emphasis upon the Victorians. Major authors may include Austen, Shelley, Dickens, Eliot, Thackeray, Gaskell, Brontë, Collins, Trollope, Stoker, Hardy. Not offered 2025-26.

En 124. 20th-Century British Fiction. *9 units (3-0-6); third term.* A survey of the 20th-century British and Irish novel, from the modernist novel to the postcolonial novel. Major authors may include Conrad, Joyce, Woolf, Forster, Lawrence, Orwell, Amis, Lessing, Rushdie. Not offered 2025-26.

En 125. British Romantic Literature. *9 units (3-0-6); second term.* A selective survey of English writing in the late 18th and early 19th centuries. Major authors may include Blake, Wordsworth, Coleridge,

Byron, Keats, Percy Shelley, Mary Shelley, and Austen. Particular attention will be paid to intellectual and historical contexts and to new understandings of the role of literature in society. Not offered 2025-26.

En 126. Gothic Fiction. *9 units (3-0-6); second term.* The literature of horror, fantasy, and the supernatural, from the late 18th century to the present day. Particular attention will be paid to gothic's shifting cultural imperative, from its origins as a qualified reaction to Enlightenment rationalism, to the contemporary ghost story as an instrument of social and psychological exploration. Issues will include atmosphere and the gothic sense of space; gothic as a popular pathology; and the gendering of gothic narrative. Fiction by Walpole, Shelley, Brontë, Stoker, Poe, Wilde, Angela Carter, and Toni Morrison. Film versions of the gothic may be included. Not offered 2025-26.

En 127. Jane Austen. *9 units (3-0-6); second term.* This course will focus on the major novels of Jane Austen: Northanger Abbey, Sense and Sensibility, Pride and Prejudice, Mansfield Park, Emma, and Persuasion. Film and television adaptations will also be considered, and students may have the opportunity to read Austen's unfinished works, as well as related eighteenth- and nineteenth-century British fiction and non-fiction. Not offered 2025-26.

En 128. Modern and Contemporary Irish Literature. *9 units (3-0-6); second term.* The development of Irish fiction, poetry, and drama from the early 20th-century Irish literary renaissance, through the impact of modernism, to the Field Day movement and other contemporary developments. Topics may include the impact of political violence and national division upon the literary imagination; the use of folk and fairy-tale traditions; patterns of emigration and literary exile; the challenge of the English language and the relation of Irish writing to British literary tradition; and recent treatments of Irish literature in regional, postcolonial, and global terms. Works by Joyce, Yeats, Synge, Friel, O'Brien, Heaney, Boland, and others. Not offered 2025-26.

En/VC 129. Literature/Photography/Facticity. *9 units (3-0-6); third term.* "It is the picture of life contrasted with the fact of life, the ideal contrasted with the real, which makes criticism possible," insists Frederick Douglass. This course will take an historical approach to the relationship between literature and photography by examining what Douglass refers to as the contrast between "picture" and "fact" from the advent of photography in the nineteenth century to our present moment. Together, we will think about how each medium creates images, invites different ways of reading or viewing, and makes forms of individual, collective, and political representation possible. We will also examine the ways in which photography and literature shape our understanding of temporality, truth, memory, and history. In addition to our experience of literary and photographic works, theoretical texts on photography will inform the ways of reading and ways of seeing we will develop in this course. Readings may include Boucicault, Douglass, Dunbar, Hartmann, Barthes, Lorde, and Rankine. Not offered 2025-26.

En 131. Poe's Afterlife. *9 units (3-0-6); second term.* This course focuses on Edgar Allan Poe and the considerable influence his works have had on other writers. Authors as diverse as Charles Baudelaire, Jules Verne, Jorge Luis Borges, Vladimir Nabokov, John Barth, and Philip Roth have used Poe's stories as departure points for their own work. We shall begin by reading some of Poe's s classic short stories, including "The Narrative of Arthur Gordon Pym," "The Purloined Letter," and others. We shall then explore how and why Poe's stories have been so important for authors, despite the fact that his reputation as a great American writer, unlike Hawthorne's and Melville's, for example, is a relatively recent phenomenon. Not offered 2025-26.

En 132. After Austen: Nineteenth-Century British Women's Writing. *9 units (3-0-6); third term.* The Victorian period introduced a huge array of new possibilities and constraints for women of all classes, as it witnessed rapid urbanization and industrialization, a changing conception of marriage and motherhood, and a new set of professional restrictions but also opportunities. This class focuses on novels by and about women, as it seeks to take the measure of these transformations and of a larger culture's reaction to them. How did women imagine and re-imagine themselves and what they wanted? How did notions of femininity and masculinity change? How do the imaginings of the Victorians resonate now? Authors studied may include Eliot, Gaskell, the Brontes, Oliphant, Braddon, and Scheiner. Not offered 2025-26.

En 133. Paradise Lost. *9 units (3-0-6); first term.* We will spend the term studying the famous and eccentric epic poem 'Paradise Lost' (1674) by the British poet and politician John Milton. Each week we will read about 1,000 to 1,500 lines of difficult but beautiful poetry, looking especially for its visual images, literary and mythological references, and poetic sounds, as well as Milton's copious and paradoxical philosophical stances. You will never forget the central character of Satan, the parliament of devils in Hell, the theological conversations in Heaven between God and Jesus, Eve being tempted by diabolical arguments to eat the forbidden fruit, and Adam and Eve being driven from the Garden of Eden at the point of an avenging angel's sword. Not offered 2025-26.

En 134. The Career of Herman Melville. *9 units (3-0-6); first term.* The course will analyze Melville's career starting with Typee and ending with Billy Budd. Special attention will be given to Moby-Dick and Pierre. The centrality of Melville's position in American literature will be considered from a variety of perspectives, including aesthetics, representations of race, class, and gender, the role of the audience, and connections with other authors. Instructor: Weinstein.

En/VC 135. Dickens's London. *9 units (3-0-6); third term.* Charles Dickens and London have perhaps the most famous relationship of any writer and city in English. In this course, we will investigate both the London Dickens knew, and the portrait of the city that he painted, by reading one of Dickens's great mid-career novels alongside a selection

of contemporary texts and images and secondary historical sources. We will think about the gap-or overlap- between history and fiction, the idea of the novelist as alternative historian, and the idea of the novel as historical document. Historical topics covered may include: the development of the Victorian police force; plague and public health; Victorian poverty; colonialism and imperialism; Dickens and his illustrators; Victorian exhibition and museum culture; and marriage and the cult of domesticity, among others. Students will practice both textual and visual analysis skills. In addition to written work, students should expect to be responsible for making a short research presentation at some point in the term. Not offered 2025-26.

En 136. The Fiction of Charles Dickens. *9 units (3-0-6);* An overview of the Great Inimitable's fiction, concentrating on four texts representative of different phases of his novel-writing career and their relationship to the changing world of Victorian Britain: Oliver Twist, Dombey and Son, Bleak House, Our Mutual Friend. Not offered 2025-26.

En 137. African American Literature. *9 units (3-0-6); second term.* This course analyzes some of the great works of American literature written by African Americans. This body of writing gives rise to two crucial questions: How does African American literature constitute a literary tradition of its own? How is that tradition inextricable from American literary history? From slave narratives to Toni Morrison's Beloved, from the Harlem Renaissance to Alice Walker, from Ralph Ellison to Walter Mosley, African American literature has examined topics as diverse and important as race relations, class identification, and family life. We shall analyze these texts not only in relation to these cultural issues, but also in terms of their aesthetic and formal contributions. Not offered 2025-26.

En 138. Twain and His Contemporaries. *9 units (3-0-6); second term.* This course will study the divergent theories of realism that arose in the period after the Civil War and before World War I. Authors covered may include Howells, James, Charlotte Perkins Gilman, Twain, Sarah Orne Jewett, Jacob Riis, Stephen Crane, and W. E. B. DuBois. Not offered 2025-26.

En 139. Ancient Greek Epic Poetry. *9 units (3-0-6); first term.* We will start the term by reading Homer's 'Iliad' (possibly 8th century B.C.) for two weeks. This is a disconnected, strange, and violent poem, which raises the excellent question how it could become a widely revered classic down to our own time. To look for answers--answers that perhaps also apply to any "classic" book-- we will go on to study the acts of interpretation, revision, and recycling that made the 'Iliad' fresh and different, sometimes virtually unrecognizable, for each new generation of readers. We survey surprising ancient Greek philosophical interpretations, a medieval romance by Geoffrey Chaucer set in ancient Troy, a fake Scottish epic poem allegedly composed by "Ossian," Chuck Palahniuk's novel 'Fight Club' (1996), and other works. My suggestion for you will be that the 'Iliad' has remained alive for millennia only through quasi-biological processes of mistranscription, mutation, and nonlinear

evolution. Not offered 2025-26.

En 140. African American Expatriate Culture in Postwar Europe. *9 units (3-0-6); second term.* In the years following World War II, an unprecedented number of African American writers and artists moved to Paris and Rome, many seeking greater personal liberties and a refuge from racial discrimination at home. As we explore literature, nonfiction, and visual culture created by African Americans in postwar Europe, we will consider: how and why does the postwar creative scene in Paris differ from that of Rome? We will analyze postwar African American expatriate writing's unique and often critical perspectives regarding American society and culture and identify the literary strategies that writers used to address the changing times, promote social justice, and advance new narrative forms, often by crossing traditional boundaries of genre and nation. Authors and artists studied may include James Baldwin, Richard Wright, Barbara Chase-Riboud, William Demby, Maya Angelou, and Ralph Ellison. Not offered 2025-26.

En 141. Science on Stage. *9 units (3-0-6); first term.* Science is no stranger to performance. There is a long tradition of presenting scientific ideas on various stages, whether for audiences comprised of experts or for a curious public, and there is an equally long tradition of integrating scientific ideas into theatrical works. In this course, we will read several scientifically informed plays, with a focus on the twentieth century. We will explore the ways in which scientific ideas shape the dialogue, plot, and staging of theatrical works and how theater can cause us to consider scientific thought from a new perspective. Readings are likely to include The Physicists (Durenmatt), Kopenhagen (Frayn), Arcadia (Stoppard), and Inherit the Wind (Lawrence and Lee), among other examples, including contemporary works. This course will also invite both scientists and playwrights into the classroom in order to enrich classroom discussions. Not offered 2025-26.

En 142. US literature before the Civil War. *9 units (3-0-6); second term.* The course will focus on the literature - what F.O. Matthiessen called "The American Renaissance" -- produced in the period leading up to the Civil War. We will consider representations of gender, race, and class, as well as the aesthetic sensibilities in works by the following: Frederick Douglass, Ralph Waldo Emerson, Harriet Jacobs, Herman Melville, Edgar Allan Poe, Harriet Beecher Stowe, and Henry David Thoreau. Not offered 2025-26.

En 149. The Literature of Crisis. *9 units (3-0-6); third term.* Novels, poetry, and memoirs often hinge on experiences of crisis. They can be individual and/or general, historically particular and/or universal: a plane crash; a war; a sudden death; a prolonged one. This course will examine representations of crisis, with a specific focus on their narrative implications. What are the temporal, spatial, and aesthetic effects of crisis? Authors covered may include Joan Didion, Percival Everett, Allen Ginsberg, Tom McCarthy, Toni Morrison, Kurt Vonnegut, Virginia Woolf, Elie Wiesel, Joy Williams. Instructor: Weinstein.

En 150. Chaos and Literature. *9 units (3-0-6); second term.* We tend to think of literary texts as models of a stable poetic order, but modern and postmodern writers conduct increasingly bold experiments to test the contrary. This class explores how writers from the nineteenth century onward draw upon ancient and contemporary concepts of chaos to test out increasingly sophisticated models of disorder though writing. Readings to include Lucretius, Serres, Calvino, Barth, Stoppard, and Kehlmann. Not offered 2025-26.

En 151. Keeping Time. *9 units (3-0-6); third term.* The way in which humans perceive and record time has a discernable history, and literary texts offer us one of the best ways to study it, particularly in times of war and natural catastrophe. With a focus on 16th- through 18th-century European literature, we will examine various techniques of literary time-keeping as they relate to topics such as, fame and mortality, as well as the experience of time's slowness and acceleration. Readings will include selections from Baroque emblem books as well as texts by Montaigne, Milton, Pepys, Defoe, and Rousseau. Not offered 2025-26.

En/VC 160 ab. Classical Hollywood Cinema. *9 units (3-0-6); third term.* This course introduces students to Hollywood films and filmmaking during the classical period, from the coming of sound through the '50s. Students will develop the techniques and vocabulary appropriate to the distinct formal properties of film. Topics include the rise and collapse of the studio system, technical transformations (sound, color, deep focus), genre (the musical, the melodrama), cultural contexts (the Depression, World War II, the Cold War), audience responses, and the economic history of the film corporations. Terms may be taken independently. Part a covers the period 1927-1940. Part b covers 1941-1960. (Part b not offered 2025-26.). Instructor: Jurca.

En/VC 161. The New Hollywood. *9 units (3-0-6); third term.* This course examines the post-classical era of Hollywood filmmaking with a focus on the late 1960s through the 1970s, a period of significant formal and thematic experimentation. We will study American culture and politics as well as film in this era, as we consider the relation between broader social transformations and the development of new narrative conventions and cinematic techniques. We will pay particular attention to the changing film industry and its influence on this body of work. Films covered may include *Bonnie and Clyde* , *The Graduate* , *The Godfather* , *Taxi Driver* , and *Jaws* . Not offered 2025-26.

En 163. Octavia E. Butler and the Literature of Black Futures. *9 units (3-0-6); third term.* This advanced humanities course begins with a selection of Octavia E. Butler's (1947-2006) novels and short stories. Born here in Pasadena, CA, Butler's writing explored issues such as chattel slavery, climate change, genetic engineering, pandemics, nuclear apocalypse, and post-apocalyptic life. She was attentive to Black and indigenous modes of care, healing, social justice, and organizing. We will pay special attention to Butler's critical and theoretical contributions to

the fields of Afrofuturism, Black studies, feminisms, gender and sexuality studies, and the environmental humanities by reading her works in conjunction with criticism and theory. In the second half of the seminar, we will explore connections between Butler and the works of other Afrofuturists and Black science fiction writers today. Finally, we will explore our own ideas for extending Butler's literature of Black futures today. Not offered 2025-26.

En 164. Contemporary Black Diasporic Literature and Culture. *9 units (3-0-6); second term.* What is a Black diasporic analytic and how might it deepen our understandings of the cultural and literary significance of Black lives around the world? The expressive genius of Black people across Black diasporas has resulted in an extensive tradition within and beyond English-speaking nations. This is an intensive advanced humanities reading course on Black diasporic literature and culture since the 1980s as well as the various histories that inform and shape this body of work. Students will read several recent works of Black diasporic literature and culture and criticism that have reshaped our understandings of family, gender, identity, labor, migration, nation, race, sexuality, and more. Students will analyze several literary and cultural works and practice writing their own Black diasporic criticism and interpretive methodologies. Not offered 2025-26.

En 165. Black Feminist and Queer Literature and Thought. *9 units (3-0-6); second term.* For centuries, Black people, especially queer and trans women, and non-binary and queer folx, writing in Africa, the Caribbean, Europe, the United States, and more, have used literature to reimagine feminisms and queerness. In the decades following the second-wave feminist movement, a body of writing necessitated the creation of "Black feminist criticism" and "queer of color critique." It was a moment in which Black people across identities and national origins wrote several works that radically retheorized family, home, gender, love, race, sexuality, work, and more, in ways that challenged cultures of violence in favor of imagining beloved communities. In this advanced humanities course, students will read, discuss, and better understand multiple literary and critical works participating in Black feminisms and Black queer thought in order to theorize new possibilities for Black futures. Not offered 2025-26.

En/VC 172. Heritage and Its Discontents. *9 units (3-0-6); first term.* What makes an old building, artifact, or custom "historic"? Which historic things are worth preserving? This course explores the aesthetic, political, social, and environmental dimensions of cultural heritage. We will examine the narratives and values associated with heritage conservation at the local level as well as within national and global contexts. From Caltech's own campus and the Watts Towers, to the national parks, UNESCO World Heritage Sites, and the culinary legacy of the Atlantic slave trade, our class will grapple with the theories, practices, and debates as they determine what gets preserved and which stories get told. Readings/screenings will be supplemented with field trips to heritage sites in Pasadena and Los Angeles. Instructor:

Jurca.

En 179. Constituting Citizenship before the Fourteenth Amendment. *9 units (3-0-6); second term.* What can a slave's narrative teach us about citizenship? How did the new nation identify citizens when its Constitution seemed so silent on the matter? And how did one tailor's pamphlet result in one of most massive restrictions of free speech in U.S. history? Our goal over the semester will be to sketch a story of African American literary production from the latter half of the eighteenth century to the Civil War and to tease out, through this literature, developing understandings of citizenship in the United States. We will read letters, poems, sermons, songs, constitutions and bylaws, short stories, and texts that simply defy easy categorization. We will also spend several sessions becoming familiar with key newspapers and magazines-Freedom's Journal, Frederick Douglass's Paper, The Anglo-African Magazine, Christian Recorder, and The Crisis-to deepen our understanding of the kinds of things people were reading and writing on a regular basis and the kinds of arguments they were making. Writers up for discussion may include: Frederick Douglass, James Madison, Harriet Jacobs, Henry David Thoreau, Sojourner Truth, and David Walker. Not offered 2025-26.

En 180. Special Topics in English. *9 units (3-0-6); offered by announcement.* This is an advanced humanities course on a specialized topic in English. It is usually taught by new or visiting faculty. The course may be re-taken for credit except as noted in the course announcement. Limited to 15 students. See registrar's announcement for details. Instructors: Staff, visitor.

En 181. Hardy: The Wessex Novels. *9 units (3-0-6); third term.* This course will examine the body of work that the late Victorian novelist Thomas Hardy published under the general title The Wessex Novels, that is, the sequence of works from Far from the Madding Crowd to Jude the Obscure. The six main novels will be read critically to give a sense of the totality of this greatest British regional novelist's achievement. Not offered 2025-26.

En 183. Victorian Crime Fiction. *9 units (3-0-6); first term.* In 19th-century Britain, for the first time in human history, more of a nation's citizens came to live in urban areas than in rural ones. This result of the Industrial Revolution produced many effects, but in the fiction of the period, one of the most striking was an obsession with the problem of crime. Victorian authors filled their novels with murder, prisons, poisonings, prostitution, criminals, and the new figure of the detective; in this class we will look at the social history, publishing developments, and formal dilemmas that underlay such a response. Authors studied may include Dickens, Collins, Braddon, Conan Doyle, Chesterton, and Conrad, among others. Not offered 2025-26.

En 185. Dickens and the Dickensian. *9 units (3-0-6);* The adjective "Dickensian" makes an almost daily appearance in today's newspapers,

magazines, and other media sources. It is used to describe everything from outrageous political scandals, to Bollywood musicals, to multiplot novels. But what does the word really mean? And what part of Charles Dickens's output does it refer to? This class will consider some of Dickens's most famous works alongside a series of contemporary novels, all critically described in "Dickensian" terms. The main concern will be equally with style and form, and 19th-century and present-day circumstances of production (e.g., serialization, mass production, Web publication, etc.). Authors considered (aside from Dickens) may include Richard Price, Zadie Smith, Monica Ali, and Jonathan Franzen. Not offered 2025-26.

En 186. The Novel of Education. *9 units (3-0-6); third term.* This class takes up a set of mostly very funny, mostly 20th century British novels to frame a simple-seeming, yet deceptively complicated set of questions: What does it mean to be educated? Who has access to education? What does an ideal education consist in? And ultimately: What is a university for? As we think through these questions we will read op/eds and investigative journalism in addition to fiction, and we will consider a variety of university-centered topics (determined by student interest) including issues of gender, class, privilege, race, and genius. Authors read may include Sayers, Larkin, Amis, C.P. Snow, Lodge, and Zadie Smith. Instructor: Gilmore.

En 190. Chaucer. *9 units (3-0-6); first term.* This course devotes itself to the writings of the diplomat, courtier, bureaucrat, and poet, Geoffrey Chaucer. Best known for the Canterbury Tales, Chaucer also authored dream visions, lyrics, and philosophical meditations. This course will introduce you to some better-known and lesser-known works in the Chaucerian corpus, while also exploring questions central to the production and circulation of literature in the fourteenth and fifteenth centuries. What did it mean to "invent" a literary work in late medieval England? How did Chaucer imagine himself as a writer and reader? What are the hallmarks of Chaucerian style, and how did Chaucer become the canonical author he is today? We will read Chaucer's works in their original language, Middle English, working slowly enough to give participants time to familiarize themselves with syntax and spelling. No previous experience with the language is necessary. Not offered 2025-26.

En/H 193. Cervantes, Truth or Dare: Don Quixote in an Age of Empire. *9 units (3-0-6); third term.* Studies Cervantes's literary masterpiece, Don Quixote, with a view to the great upheavals that shaped the early modern world: Renaissance Europe's discovery of America; feudalism's demise and the rise of mass poverty; Reformation and Counter-Reformation; extermination of heretics and war against infidels; and the decline of the Hapsburg dynasty. The hapless protagonist of Don Quixote calls into question the boundaries between sanity and madness, truth and falsehood, history and fiction, objectivity and individual experience. What might be modern, perhaps even revolutionary, in Cervantes's dramatization of the moral and material dilemmas of his time?

Conducted in English. Instructor: Wey-Gomez.

En 194. There and Back Again: Ancient and Early Modern Epic Storytelling. *9 units (3-0-6); first term.* This course will examine how ancient and early modern epic poems variously imagine the processes of identity formation, as well as how narrative construction and figurative language shape the interpretive possibilities of these epics. With memorable protagonists to guide us-from Odysseus and Aeneas to Dante, Britomart, and Adam and Eve-we will analyze how the epic tradition vividly investigates rhetoric and identity, insists on the social and cultural power of storytelling, and asks us to consider how we come to know ourselves and the communities to which we belong. Students will develop skills in reading, analyzing, and writing arguments about these complex and historically significant poems. Texts will include Homer's Odyssey and Virgil's Aeneid in full, and selections from Dante's Inferno, Spenser's Faerie Queene, and Milton's Paradise Lost. Instructor: Morstein.

En 195. Virtual Realities. *9 units (3-0-6); first term.* Dreams, projections, simulacra, literary fantasy, and - more recently - VR headsets: they all tap into the notion of a virtual reality, one whose relation to the "real" world is not always easy to discern. What does it mean for something to be "virtually" or "nearly" real? In this course, we take a broad look at this question and consider virtual reality from various historical perspectives (including Plato's Cave Allegory, Descartes' Meditations, and Calderon's Life is a Dream) before focusing on more recent literary approaches within the context of the rapidly changing technological environment. Further readings will likely include Borges, Baudrillard, Le Guin, Bateson, and Hayles. Students will also complete a short project on a fantasy novel of their choice. Instructor: Holland.

En 196. Introduction to Asian American Literature and Theory. *9 units (3-0-6); first term.* This course will provide an introduction to Asian American literature and theory. We will explore literary productions as a site to interrogate the aspirations and contradictions of the rubric of 'Asian America'. What does it mean to be Asian American? How can we think about the racial politics of Asian America in relation to class, gender, and other social determinants? Course readings will feature a mix of classic and contemporary Asian American fiction, poetry, and theory. Authors may include Maxine Hong Kingston, Karen Tei Yamashita, Solmaz Sharif, and Franny Choi. Instructor: Li.

En/VC 197. The Urban Environmental Imagination. *9 units (3-0-6); third term.* This class looks at the material and imagined facets of nature in the city. To begin, we will trace an overview of ideas about nature in urbanist discourse, starting with works from canonical figures such as Frederick Law Olmsted and carrying forward to discussions of environmental justice, political ecology, and multi-species urbanism. Alongside this critical introduction, we will turn to artworks that challenge urbanist conventions and pose imaginative possibilities at the intersection of nature, culture, and the city. Our efforts will fall between

disciplines-critical urbanism, cultural studies, and the environmental humanities-and Los Angeles will play a starring role. Not offered 2025-26. .

En/VC 198. Graphic Non-Fiction: Memoir, History, and Journalism. *9 units (3-0-6); second term.* For a long time, comics were trivialized as a form of popular entertainment. Graphic novels helped change that, and now it's widely recognized that comics can, indeed, rise to the level of literature. In this class we will look at comics that tell "true stories"-ones that draw on the imaginative interplay between image and text to illuminate the layers of lived experience. We will ask what comics can do that conventional literary forms cannot and explore how authors like Art Spiegelman, Alison Bechdel, and Joe Sacco have utilized the comics toolkit to write personal stories, rewrite history, and report the news. In addition to class discussion and written assignments, we will do some low-stakes drawing and storytelling exercises. Instructor: Earhart.

En/VC 199. Shakespeare at the Cinema. *9 units (3-0-6); second term.* This course will teach you how to read Shakespeare by studying the texts of four plays alongside eight cinematic adaptations. We will discuss Shakespeare's great subjects, such as love, tyranny, revenge, and redemption, and we will analyze how the medium of film reimagines Shakespeare's drama across vastly different settings in time and space, from mansions in Verona Beach and chicken rice stalls in Singapore to feudal Japan and outer space in the 23rd-century. We will learn about the performance conventions of Shakespeare's time, examine interpretive choices in the films and propose our own, and develop our skills of attention to various forms of media as we write about the plays, act them out, and try our hand at making short clips. Plays will include Romeo and Juliet, Hamlet, Macbeth, and The Tempest. Instructor: Morstein.

ENGLISH AS A SECOND LANGUAGE

ESL 101 ab. Oral Communication and Presentation. *3 units (3-0-0); first, second terms.* This course focuses on preparing non-native speakers of English with the communication skills necessary to organize, present or exchange information in a clear, concise manner to a variety of audiences. ESL 101 a will provide instruction on the development of pronunciation, intonation patterns and stress, grammar and verb tense, listening comprehension, and fluency in speaking. Aspects of American culture as well as come current events will be discussed. ESL 101 b is a continuation of ESL 101 a, and covers a variety of oral presentation skills. Students will be asked to paraphrase, summarize, and synthesize information from a journal article or in-class discussions and communicate ideas to the class. The class will discuss information from readings and other media sources in small groups to collect and organize ideas for discussion. ESL 101 ab is open to all first-year graduate students and may be required for some students designated by

the ESL interview process during Orientation. A passing grade will satisfy the Institute English proficiency requirement for candidacy. Graded pass/fail. Open to international graduate students only.

ESL/Wr 107. Fundamentals of Scientific Writing. *6 units (3-0-3); third term.* This course aims to provide a strong scientific writing foundation for multilingual or international graduate students through guided instruction in academic STEM writing. More specifically, it teaches graduate students about composing texts in scientific English for various audiences, focusing on issues of clarity, as well as grammar and usage. It helps familiarize writers with the features of clear and effective STEM writing, and it teaches writers about the style and genres of U.S. academic STEM writing, helping them learn to read and write about the work of others in their field. Students are encouraged to take ESL/Wr 107 in the first or second year of graduate school. Instructor: Manoukian.

ENVIRONMENTAL SCIENCE & ENGINEERING

ESE 1. Earth's Climate. *9 units (3-0-6); second term.* An introduction to climate on Earth. How Earth's climate has changed in the past and its evolving response to the rapid increase in carbon dioxide and methane happening today. Model projections of future climate and associated risks. Development of climate policies in face of uncertainty in these projections and risks. Enrollment is limited. Satisfies the menu requirement of the Caltech core curriculum. Juniors and Seniors who have satisfied their menu course requirement should enroll in ESE 101. Instructor: Wennberg.

FS/ESE/Ge 18. First-Year Seminar: The Unseen Microbial World in Plain Sight. *6 units (2-0-4);* For course description, see First-Year Seminars

ESE/Ge 21. Tutorial: Biogeochemistry of Carbon Sequestration. *9 units (2-0-7); first term.* The impact of greenhouse gases on Earth's climate has led to development of a variety of strategies for sequestering carbon from the atmosphere. These include pumping carbon dioxide into geologic reservoirs or ultramafic rocks, stimulating biospheric growth, enhanced mineral weathering, soil carbon accumulation, biomass burial on land or at sea, and others. We will examine these strategies in detail, looking at both the science and technology that enable them to work, as well as their potential biogeochemical ramifications for Earth's global systems if pursued at scale. The class is structured as a tutorial, in which small groups of students meet individually with the instructor, and topics are presented by the students. Each student will write papers, give presentations, and lead discussions on 3 topics throughout the term. Course will be limited to 12 participants, who will be selected at the start of the term based on background, interests, and willingness to commit

to the entire term. Undergrads only. Fulfills the Institute scientific writing requirement. Instructor: Sessions.

ESE 90. Undergraduate Laboratory Research in Environmental Science and Engineering. *Units by arrangement; any term.* Approval of research supervisor required prior to registration. Independent research on current environmental problems; laboratory or field work is required. A written report is required for each term of registration. Graded pass/fail. Instructor: Staff.

ESE 91. Senior Thesis Research. *9 units; third term. Prerequisites: ESE 90 and Instructor's permission.* Two terms of ESE 90 are to be completed during the junior and/or senior year of study. At the end of the third term, students enrolled in ESE 91 will present a thesis of approximately 20 pages (excluding figures and references) to the mentor and the ESE Option Representative. The thesis must be approved by both the research mentor and the ESE faculty. An oral thesis defense will be arranged by the ESE Option Representative in the third term for all enrollees. All prior terms of ESE 90 will be taken on a pass/fail basis, but the third term of ESE 91 will carry a letter grade. Instructor: Staff.

ESE 100. Special Problems in Environmental Science and Engineering. *Up to 12 units by arrangement; any term. Prerequisites: instructor's permission.* Special courses of readings or laboratory instruction. Graded pass/fail. Instructor: Staff.

ESE 101. Earth's Atmosphere. *9 units (3-0-6); first term.* Introduction to the fundamental processes governing atmospheric circulations and climate. Starting from an overview of the observed state of the atmosphere and its variation over the past, the course discusses Earth's radiative energy balance including the greenhouse effect, Earth's orbit around the Sun and climatic effects of its variations, and the role of atmospheric circulations in maintaining the energy, angular momentum, and water balances, which determine the distributions of temperatures, winds, and precipitation. The focus throughout is on order-of-magnitude physics that is applicable to climates generally, including those of Earth's past and future and of other planets. Instructor: Schneider.

ESE 102. Earth's Oceans. *9 units (3-0-6); first term.* This course will provide a basic introduction to physical, chemical, and biological properties of Earth's ocean. The course is divided into three parts that address various aspects of the marine carbon cycle, including carbon and tracer transport by the ocean circulation, carbonate chemistry, and fixation/respiration of carbon by biological processes. These parts are tied to three key questions that highlight the ocean's role in the global climate system: What processes contribute to changes in global and local sea level? How and where does the ocean exchange carbon dioxide with the atmosphere? Why is a warming climate associated with ocean acidification and what are the biological consequences? The course will also provide perspectives on how we observe and model the ocean and how these tools are used in climate predictions. Instructor:

Thompson.

ESE 103. Earth's Biogeochemical Cycles. *9 units (3-0-6); second term.* Provide a basic introduction to Global Biogeochemical cycles, with a focus on drivers of the global biosphere. Topics to be covered include fundamentals of photosynthesis and its quantitative formulation, impact of nutrients, microbial processes underlying weathering, decomposition, and carbon remineralization, box modeling, hydrological cycle, land surface energy balance and basics of land surface modeling, ecosystem processes and the human footprint. Some basic scientific computing (Python/Julia) knowledge is required for homework sets. Instructor: Frankenberg.

ESE 104. Current Problems in Environmental Science and Engineering. *1 unit; second term.* Discussion of current research by ESE graduate students, faculty, and staff. Instructor: Callies.

Bi/Ge/ESE 105. Evolution. *12 units (3-4-5);* For course description, see Biology

ESE 106. Research in Environmental Science and Engineering. *Units by arrangement; any term. Prerequisites: instructor's permission.* Exploratory research for first-year graduate students and qualified undergraduates. Graded pass/fail. Instructor: Staff.

ESE 110 abc. Seminar in Environmental Science and Engineering. *1 unit; first, second, third terms.* Required attendance by first year graduate students at the weekly ESE seminar, Wednesdays 4pm. Graded pass/fail. Instructor: Karthikeyan.

ChE/ESE/ME/MS 111. Sustainable Engineering. *9 units (3-0-6);* For course description, see Chemical Engineering

BEM/Ec/ESE 119. Environmental Economics. *9 units (3-0-6);* For course description, see Business Economics & Management

Ge/ESE 125. Earth's Landscapes. *12 units (3-5-4);* For course description, see Geology

ESE/Ge 129. Soil Systems Microbiology. *9 units (3-3-3); first term.* Soils harbor some of the most diverse microbiomes on Earth. Microorganisms play key roles in soil carbon (C) and nutrient turnover and the generation of persistent organic matter via their metabolic activities, cellular biochemistry, and extracellular products. Soil microbes also provide rich elemental and genetic resources to their predators, including phages, bacteria, and microfauna. The course will cover topics related to studying the interactions and functions of the entire microbial community within soil, focusing on tools used to measure the community diversity, the ecology and micro-scale interactions, and the ecosystem functions soil microorganisms modulate. Through a combination of lectures, laboratory work, and computational analyses, students will learn how

microbial communities in soil ecosystems cycle element pools (mainly C and N) and how phages modulate bacterial populations and these cycles. Instructor: Karthikeyan.

ESE 130. Fundamentals of Atmosphere and Ocean Dynamics. *9 units (3-0-6); second term. Prerequisites: ESE 101 and ESE 102 recommended and Ma 2 or equivalent (instructor's permission).* This course is an introduction to the fluid dynamics of the atmosphere and ocean, with an emphasis on dynamical concepts that explain the large-scale circulation of both fluids. Starting from the equations of motion, we will develop an understanding of geostrophic and hydrostatic balance, inertia-gravity waves, geostrophic adjustment, potential vorticity, quasi-geostrophic dynamics, Rossby waves, baroclinic instability, and Ekman layers. Instructor: Callies.

ESE 131. Ocean Dynamics. *9 units (3-0-6); third term. Prerequisites: ESE 102 and ESE 130, or instructor's permission.* This course gives an in-depth discussion of the fluid dynamics of the world ocean. Building on the concepts developed in ESE 130, this course explores the vertical structure of the wind-driven gyre circulation, thermocline theory, the dynamics of the Southern Ocean, eddies and eddy parameterizations, geostrophic turbulence, submesoscale dynamics, the circulation of the deep ocean, tides, internal waves, and turbulent mixing. Offered 2025-26. Instructor: Callies.

ESE 132. Tropical Atmosphere Dynamics. *9 units (3-0-6); third term. Prerequisites: ESE 101 and ESE 130, or instructor's permission.* Phenomenological description of tropical atmospheric circulations at different scales, and theories or models that capture the underlying fundamental dynamics, starting from the large-scale energy balance and moving down to cumulus convection and hurricanes. Topics to be addressed include: large-scale circulations such as the Hadley, Walker, and monsoonal circulations, the intertropical convergence zone, equatorial waves, convectively coupled waves, and hurricanes. Given in alternate years; not offered 2025-26. Instructor: Schneider.

ESE 133. Global Atmosphere Dynamics. *9 units (3-0-6); third term. Prerequisites: ESE 101 and ESE 130, or instructor's permission.* Introduction to the global-scale fluid dynamics of atmospheres, beginning with a phenomenological overview of observed circulations on Earth and other planets and leading to currently unsolved problems. Topics include constraints on atmospheric circulations and zonal winds from angular momentum balance; Rossby wave generation, propagation, and dissipation and their roles in the maintenance of global circulations; moist convection and its coupling to waves and circulations; Hadley circulations and tropical-extratropical interactions; energy cycle and thermodynamic efficiency of atmospheric circulations. The course focuses on Earth's atmosphere but explores a continuum of possible planetary circulations and relationships among them as parameters such as the planetary rotation rate chance. Not offered 2025-26. Instructor: Schneider.

ESE 134. Cloud and Boundary Layer Dynamics. *9 units (3-0-6); third term. Prerequisites: ESE 101 or instructor's permission.* Introduction to the dynamics controlling boundary layers and clouds and how they may change with climate, from a phenomenological overview of cloud and boundary layer morphologies to closure theories for turbulence and convection. Topics include similarity theories for boundary layers; mixed-layer models; moist thermodynamics and stability; stratocumulus and trade-cumulus boundary layers; shallow cumulus convection and deep convection. Instructor: Schneider.

ESE 135. Topics in Atmosphere and Ocean Dynamics. *3 units (1-0-2); third term. Prerequisites: ESE 101 or ESE 102, or instructor's permission or equivalent.* A lecture or discussion course on current research in atmosphere and ocean dynamics. Topics covered vary from year to year and may include global circulations of planetary atmospheres, geostrophic turbulence, atmospheric convection and cloud dynamics, wave dynamics and large-scale circulations in the tropics, marine physical-biogeochemical interactions, dynamics of the El Nino Southern Oscillation, and global warming. Not offered 2025-26. Instructor: Staff.

ESE 136. Climate Models. *6 units (2-0-4); third term. Prerequisites: ESE 101 or ESE 102, or instructor's permission.* The course covers the architecture and scientific underpinnings of models of the atmosphere, ocean, land, and ice, numerical methods for the underlying differential equations, aspects of high-performance computing, and model calibration (both manual and machine-learned). Overviews of theoretical concepts will be combined with hands-on exercises in running a state-of-the-art climate model, and analyzing and understanding its output. The course will enable students to design their own model experiments and to evaluate the results critically. Not offered 2025-26. Instructor: Schneider.

ESE 137. Polar Oceanography. *9 units (3-0-6); third term. Prerequisites: ESE 131 or instructor's permission.* This course focuses on high latitude processes related to the Earth's oceans and their interaction with the cryosphere, including glaciers, ice shelves and sea ice. The course starts with introductory lectures related to regional circulation features, water mass modification and ice dynamics. The second half of the course will focus on a single topic, with input from the students, and will be explored in detail through the scientific literature and through individual projects. not offered 2025-26. Instructor: Thompson.

ESE 138. Waves in Geophysical Fluids. *9 units (3-0-6); first term. Prerequisites: ESE 131 or instructor's permission.* This course offers an in-depth discussion of waves in fluids, with a focus on rotating and stratified fluids and applications to the ocean. Topics include dispersive and non-dispersive wave propagation, propagation in inhomogeneous media, WKB approximation and ray tracing, elements of wave-mean flow interaction theory. These principles will be applied to sound waves, surface gravity waves, internal gravity waves, and Rossby waves.

Consequences for the general circulation of the ocean and opportunities for observing the ocean will serve as motivation. not offered 2025-26. . Instructor: Callies.

Ge/ESE 139. Introduction to Atmospheric Radiation. *9 units (3-0-6);* For course description, see Geology

Ge/ESE 140 c. Stable Isotope Biogeochemistry. *9 units (3-0-6);* For course description, see Geology

ESE/Ge/Ch 142. Aquatic Chemistry of Natural Waters. *9 units (3-0-6); third term. Prerequisites: Ch 1 or instructor's permission.* Inorganic chemistry of natural waters with an emphasis on equilibrium solutions to problems in rivers, lakes, and the ocean. Topics will include, acid-base chemistry, precipitation, complexation, redox reactions, and surface chemistry. Examples will largely be drawn from geochemistry and geobiology. Selected topics in kinetics will be covered based on interest and time. Instructor: Zakem.

Ge/ESE 143. Organic Geochemistry. *9 units (3-2-4);* For course description, see Geology

ESE 144. Climate from Space. *9 units (3-0-6); third term.* This class will provide an overview of how we study the Earth's climate system using satellite remote sensing; a series of core lectures and guest lectures will be jointly taught by Caltech faculty and JPL scientists. Topics that will be covered include Introduction to the climate system; introduction to radiative transfer, retrieval methods and data assimilation; Earth's energy balance; atmospheric physics and composition; ocean dynamics and ice physics; monitoring the carbon cycle from space. Offered 2025-26. Instructors: Teixeira, Thompson.

ME/CE/Ge/ESE 146. Computational Methods for Flow in Porous Media. *9 units (3-0-6);* For course description, see Mechanical Engineering

Ge/Bi/BE/CNS/ESE 147. Challenges and Opportunities in Quantitative Ecology. *6 units (6-0-0);* For course description, see Geology

Ge/ESE 149. Marine Geochemistry. *9 units (3-0-6);* For course description, see Geology

Ge/ESE 150. Planetary Atmospheres. *9 units (3-0-6);* For course description, see Geology

Ge/ESE 154. Readings in Paleoclimate. *3 units (1-0-2);* For course description, see Geology

Ge/ESE 155. Paleoceanography. *9 units (3-0-6);* For course description, see Geology

ESE 156. Remote Sensing of the Atmosphere and Biosphere. *9 units (3-0-6); third term. Prerequisites: ESE 101 or instructor's permission.* An introduction into methods to quantify trace gases as well as vegetation properties remotely (from space, air-borne or ground-based). This course will provide the basic concepts of remote sensing, using hands-on examples to be solved in class and as problem-sets. Topics covered include Absorption spectroscopy, measurement and modeling techniques, optimal estimation theory and error characterization, applications in global studies of biogeochemical cycles and air pollution/quality. This course is complementary to EE/Ae 157 ab and Ge/EE/ESE 157 c with stronger emphasis on applications for the atmosphere and biosphere. Students will work with real and synthetic remote sensing data (basic knowledge of a scripting language is required, most of the examples will be in Julia). Instructor: Frankenberg.

Ge/EE/ESE 157 c. Remote Sensing for Environmental and Geological Applications. *9 units (3-3-3);* For course description, see Geology

ESE/ChE 158. Aerosol Physics and Chemistry. *9 units (3-0-6); third term.* Fundamentals of aerosol dynamics and their description using population balance equations: particle size and property distributions in aerosol systems. Physical and chemical mechanisms that govern the aerosol dynamics from the continuum through free-molecular regimes: condensation and evaporation; nucleation; particle aerodynamics and diffusion. Thermodynamic, physical, and optical properties of aerosol particles. Instructor: Flagan.

ESE/Bi 166. Microbial Physiology. *9 units (3-1-5); first term. Prerequisites: one year of general biology recommended.* A course on growth and functions in the prokaryotic cell. Topics covered: growth, transport of small molecules, protein excretion, membrane bioenergetics, energy metabolism, motility, chemotaxis, global regulators, and metabolic integration. Instructor: Leadbetter.

ESE/Bi 168. Microbial Metabolic Diversity. *9 units (3-0-6); second term. Prerequisites: ESE 142, ESE/Bi 166.* A course on the metabolic diversity of microorganisms. Basic thermodynamic principles governing energy conservation will be discussed, with emphasis placed on photosynthesis and respiration. Students will be exposed to genetic, genomic, and biochemical techniques that can be used to elucidate the mechanisms of cellular electron transfer underlying these metabolisms. Given in alternate years; not offered 2025-26. Instructor: Newman.

ESE/Ge/Ch 171. Atmospheric Chemistry I. *9 units (3-0-6); second term. Prerequisites: Ch 1 or equivalent.* A detailed course about chemical transformation in Earth's atmosphere. Kinetics, spectroscopy, and thermodynamics of gas-phase chemistry of the stratosphere and troposphere; sources, sinks, and lifetimes of trace atmospheric species; stratospheric ozone chemistry; oxidation mechanisms in the troposphere; aerosol chemistry. Instructor: Wennberg.

ESE/Ch 176. Environmental Physical Organic Chemistry. *9 units (3-0-6); second term. Prerequisites: Ch 41 ab or instructor's permission.* This course will cover selected aspects of the chemistry of aquatic systems. Lectures cover basic principles of physical-organic chemistry relevant to the aquatic environment under realistic conditions. Specific topics covered in this course include the basic principles of equilibrium chemical and physical processes important for natural waters. Topics include: chemical potential, fugacity, phase transfer, acid-base chemistry, metal-ligand substitution chemistry, surface chemistry, octanol-water partitioning, air-water partitioning, partitioning to solid organic matter and biomedia, sorption processes, air-water exchange dynamics, and the kinetics and mechanisms of coupled organic and inorganic redox reactions. Thermodynamics, transport, phase transfer and kinetics are emphasized. Instructor: Diallo.

Ge/ESE/Bi 178. Microbial Ecology. *9 units (3-2-4);* For course description, see Geology

ESE/ME/EST/Ec/ChE/EE 179. Climate Change Impacts, Mitigation and Adaptation. *3 units (3-0-0); second term.* Climate change has already begun to impact life on the planet, and will continue in the coming decades. This class will explore particular causes and impacts of climate change, technologies to mitigate or adapt to those impacts, and the economic and social costs associated with them - particular focus will be paid to distributional issues, environmental and racial justice and equity intersections. The course will consist of 3-4 topical modules, each focused on a specific impact or sector (e.g. the electricity or transportation sector, climate impacts of food and agriculture, increasing fires and floods). Each module will contain lectures/content on the associated climate science background, engineering/technological developments to combat the issue, and an exploration of the economics and the inequities that exacerbate the situation, followed by group discussion and synthesis of the different perspectives. Instructors: Wennberg, Staff.

ESE/Ge/Bi/ChE 184. Computational Tools for Decoding Microbial Ecosystems. *9 units (3-0-6); second term. Prerequisites: Prior knowledge in Microbiology/Microbial Ecology is required (or instructor's approval). Proficiency in python, bash, slurm, while encouraged, is not required.* Microbes, the most diverse and abundant organisms on Earth, are critical to the daily functioning of humans as well as the life-sustaining biogeochemical cycles. This course provides an in-depth exploration of the fascinating world of environmental microbiology and genomics, with a special emphasis on computational approaches for systems-level analysis of microbial communities and their interactions. The course will delve into the diverse roles of microorganisms in environmental processes ranging from nutrient and biogeochemical cycling to predicting the impacts of climate change. It will introduce students to a wide range of computational tools and techniques used in the analysis of microbial genomic data. Topics covered include: microbial community structure and functioning; interactions among

microbes and their environment; and the influence of the environment in shaping and driving microbial evolution. Through a combination of lectures, discussions, and hands-on computational exercises, students will gain skills in analyzing, interpreting and visualizing large scale community metagenomic (DNA) and metatranscriptomic (RNA) data from environmental ecosystems. Students will also explore how these computational approaches can be applied to address real-world environmental challenges, broaden understanding of the genetic and metabolic diversity of the microorganisms to better manage ecosystem function, the value of this biodiversity for adaptation to natural and anthropogenic perturbations. Instructor: Karthikeyan.

ESE 200. Advanced Topics in Environmental Science and Engineering. *Units by arrangement; any term.* Course on contemporary topics in environmental science and engineering. Topics covered vary from year to year, depending on the interests of the students and staff.

Ge/Bi/ESE 246. Molecular Geobiology Seminar. *6 units (2-0-4);* For course description, see Geology

Ge/ESE/Bi 248. Environmental Justice. *6 units (2-0-4);* For course description, see Geology

Ge/Bi/ESE/CE 249. Stable Isotopes: Ecological and Environmental Applications. *9 units (3-3-3);* For course description, see Geology

Ge/ESE 298. Mentoring and Outreach. *Units to be arranged, up to 12 units per year;* For course description, see Geology

ESE 300. Thesis Research. *Units by arrangement; any term.* Thesis research for graduate students after passing the qualifying exam. Graded pass/fail. Instructor: Staff.

FIRST-YEAR SEMINARS

FS 2. The Evolution of Information Systems: From Life to Artificial Intelligence. *6 units (2-0-4); second term.* What is life? What is special about the human brain? How did the invention of writing enable the transition from human intelligence to artificial intelligence? We will argue that life is an information system that has memory stored in syntax (DNA) that is enriched by an innovation process (mutation and selection) that leads to new species. Also, we will argue that the human brain is an information system that has memory (enabled by natural languages) that is enriched by an innovation process (learning) that leads to new ideas. The emergence of life and the human brain served as the backdrop to the information (r)evolution that we are witnessing today!. Instructor: Bruck.

FS/Ay 3. First-Year Seminar: Automating Discovering the Universe. *6 units (2-0-4);* Powerful new instruments enable astronomers to collect huge volumes of data on billions of objects. As a result, astronomy is changing dramatically: by the end of this decade, most astronomers will probably be analyzing data collected in large surveys, and only a few will still be visiting observatories to collect their own data. The tool chest of future astronomers will involve facility with "big data", developing clever queries, algorithms (some based on machine learning) and statistics, and combining multiple databases. This course will introduce students to some of these tools. After "recovering" known objects, students will be unleashed to make their own astronomical discoveries in new data sets. Limited enrollment. Not offered 2025-26.

FS/Ph 4. First-Year Seminar: Astrophysics and Cosmology with Open Data. *6 units (2-0-4); first term.* Astrophysics and cosmology are in the midst of a golden age of science-rich observations from incredibly powerful telescopes of various kinds. The data from these instruments are often freely available on the web. Anyone can do things like study x-rays from pulsars in our galaxy or gamma rays from distant galaxies using data from Swift and Fermi; discover planets eclipsing nearby stars using data from Kepler; measure the expansion of the universe using supernovae data; study the cosmic microwave background with data from Planck; find gravitational waves from binary black hole mergers using data from LIGO; and study the clustering of galaxies using Hubble data. We will explore some of these data sets and the science that can be extracted from them. A primary goal of this class is to develop skills in scientific computing and visualization. Bring your laptop!. Instructor: Weinstein.

FS/Ph 9. The Science of Music. *6 units (2-0-4); first term.* This course will focus on the physics of sound, how musical instruments make it, and how we hear it, including readings, discussions, demonstrations, and student observations using sound analysis software. In parallel we will consider what differentiates music from other sounds, and its role psychically and culturally. Students will do a final project of their choice and design, with possibilities including analysis of recordings of actual musical instruments, instrument construction and analysis, and tests or surveys of people's abilities or preferences. Open to all undergraduates, i.e., 1st, 2nd, 3rd and 4th year. Instructor: Politzer.

FS/Ph 11 abc. First-Year Seminar: Beyond Physics. *6 units (2-0-4); second, third terms of a first-year student's first year and first term of sophomore year.* First-year students are offered the opportunity to enroll in this class by submitting potential solutions to problems posed in the fall term. A small number of solutions will be selected as winners, granting those students permission to register. This course demonstrates how research ideas arise, are evaluated, and tested and how the ideas that survive are developed. Weekly group discussions and one-on-one meetings with faculty allow students to delve into cutting edge scientific research. Ideas from physics are used to think about a huge swath of problems ranging from how to detect life on extrasolar

planets to exploring the scientific underpinnings of science fiction in Hollywood films to considering the efficiency of molecular machines. Support for summer research at Caltech between an undergraduate's first and sophomore years will be automatic for students making satisfactory progress. Graded pass/fail. First-year (undergraduates) only; limited enrollment. Instructor: Phillips.

FS/Ma 12. First-Year Seminar: The Mathematics of Enzyme Kinetics. *6 units (2-0-4); third term. Prerequisites: Ma 1 ab.* Enzymes are at the heart of biochemistry. We will begin with a down to earth discussion of how, as catalysts, they are used to convert substrate to product. Then we will model their activity by using explicit equations. Under ideal conditions, their dynamics are described by a system of first order differential equations. The difficulty will be seen to stem from them being non-linear. However, under a steady state hypothesis, they reduce to a simpler equation, whose solution can describe the late time behavior. The students will apply it to some specially chosen, real examples. Not offered 2025-26.

FS/Ph 15. First-Year Seminar: Quantum Information Science Today and Tomorrow. *6 units (2-0-4); second term.* Quantum information science is transforming our understanding of the physical world and pointing toward revolutionary future technologies. We will explore the conceptual foundations of this rapidly advancing field. Topics to be discussed include quantum entanglement, Bell inequalities, decoherence, quantum metrology, quantum computing, quantum error correction, and quantum cryptography. Instructor: Preskill.

FS/Ge 16. First-year Seminar: Earthquakes. *6 units (2-0-4); first term.* Earthquakes and volcanic eruptions constitute some of the world's major natural hazards. What is the science behind prediction and/or rapid response to these events? We will review the current understanding of the science, the efforts that have been made in earthquake and volcano forecasting, and real-time response to these events. We will learn about advances in earthquake preparation in Southern California, and volcanic eruption forecasting and hazard mitigation elsewhere. There is a required field trip to visit faults and volcanoes somewhere in southern California. First-year (undergraduates) only; limited enrollment. Instructor: Stock.

FS/ESE/Ge 18. First-Year Seminar: The Unseen Microbial World in Plain Sight. *6 units (2-0-4); first term.* To paraphrase a Caltech engineering colleague: "In terms of Earth and the Environment, our species had been nothing more than the hood ornament on a really interesting car. We should be studying what's under the hood, the microbial world, if we want to understand the engine". We will spend the term examining striking examples of microbes and microbial activities in the environment. First-year (undergraduates) only; limited enrollment. Instructor: Leadbetter.

FS/Ge 20. First-Year Seminar: Life in the Universe. *6 units (2-0-4); first term.* For now, Earth remains the only place in the universe where life is

known to exist, but recent advances in planetary exploration and astronomical observation could change that in the near future. We will explore the conditions that led to life on Earth and will investigate the history of our own biosphere. We will look at the current techniques used to understand where conditions might be amenable for life to have arisen elsewhere, and we will discuss the prospects for detection of such life in the future at places including Mars, Europa, Titan, and planets around other stars. This course will bring in ideas and techniques from biology, geology, planetary science, and astronomy to allow us to address -- and perhaps some day answer -- the millennia-old question of whether or not we are alone in the universe. First-year (undergraduates) only; limited enrollment. Instructor: Brown.

GEOLOGY

Ge 1. Earth and Environment. *9 units (3-3-3); third term.* An introduction to the ideas and approaches of earth and planetary sciences, including both the special challenges and viewpoints of these kinds of science as well as the ways in which basic physics, chemistry, and biology relate to them. In addition to a wide-ranging lecture-oriented component, there will be a required field trip component. The lectures and topics cover such issues as solid Earth structure and evolution, plate tectonics, oceans and atmospheres, climate change, and the relationship between geological and biological evolution. Not offered on a pass/fail basis. Satisfies the menu requirement of the Caltech core curriculum. Instructor: Fischer.

IC/Ge 1 abc. Integrated Core: Energy, Climate, and Carbon. *1 units (1-0-0); 2 units (1-1-0); 6 units (2-3-1);* For course description, see Integrated Core

Ge 11 a. Introduction to Earth and Planetary Sciences: Earth as a Planet. *9 units (3-3-3); first term.* A broad introduction to the physical and chemical processes that have shaped Earth as a planet over geological time, and the observable products of these processes. Topics covered include Earth's internal structure, plate tectonics, minerals, igneous rocks and magmatism, metamorphic rocks and metamorphism, weathering, erosion, and sedimentary rocks, rock deformation, earthquakes, streams and drainage systems, groundwater, glaciers and glaciation, the oceans and their margins, climate change, geologic resources, geologic time and Earth history. The course includes an overnight field trip and a weekly laboratory section. Although Ge 11 abcd is designed as a sequence, any one term may be taken as a standalone course. Instructor: Bucholz.

Ge 11 b. Introduction to Earth and Planetary Sciences: Earth and the Biosphere. *9 units (3-3-3); second term. Prerequisites: Ch 1 a.* Systematic introduction to the origin and evolution of life and its impact on the oceans, atmosphere, and climate of Earth. Topics covered

include ancient Earth surface environments and the rise of atmospheric oxygen. Microbial and molecular evolution, photosynthesis, genes as fossils. Banded iron stones, microbial mats, stromatolites, and global glaciation. Biological fractionation of stable isotopes. Numerical calibration of the geological timescale, the Cambrian explosion, mass extinctions, and human evolution. The course usually includes one major field trip and laboratory studies of rocks, fossils, and geological processes. Although Ge 11 abcd is designed as a sequence, any one term may be taken as a standalone course. Biologists are particularly welcome. Instructor: Tejada.

Ge/Ay 11 c. Introduction to Earth and Planetary Sciences: Planetary Sciences. *9 units (3-0-6); third term. Prerequisites: Ma 1 ab, Ph 1 ab.* A broad introduction to the present state and early history of the solar system, including terrestrial planets, giant planets, moons, asteroids, comets, and rings. Earth-based observations, observations by planetary spacecraft, study of meteorites, and observations of extrasolar planets are used to constrain models of the dynamical and chemical processes of planetary systems. Although Ge 11 abcd is designed as a sequence, any one term may be taken as a standalone course. Physicists and astronomers are particularly welcome. Instructor: Brown.

Ge 11 d. Introduction to Earth and Planetary Sciences: Geophysics. *9 units (3-0-6); second term. Prerequisites: Ch 1, Ma 2 a, Ph 2 a.* An introduction to the geophysics of the solid earth; formation of planets; structure and composition of Earth; interactions between crust, mantle, and core; surface and internal dynamics; mantle convection; imaging of the interior; seismic tomography. Although Ge 11 abcd is designed as a sequence, any one term can be taken as a standalone course. Instructor: Gurnis.

FS/Ge 16. First-year Seminar: Earthquakes. *6 units (2-0-4);* For course description, see First-Year Seminars

FS/ESE/Ge 18. First-Year Seminar: The Unseen Microbial World in Plain Sight. *6 units (2-0-4);* For course description, see First-Year Seminars

FS/Ge 20. First-Year Seminar: Life in the Universe. *6 units (2-0-4);* For course description, see First-Year Seminars

ESE/Ge 21. Tutorial: Biogeochemistry of Carbon Sequestration. *9 units (2-0-7);* For course description, see Environmental Science & Engineering

Ge 40. Special Problems for Undergraduates. *Units to be arranged; any term.* This course provides a mechanism for undergraduates to undertake honors-type work in the geologic sciences. By arrangement with individual members of the staff. Graded pass/fail.

Ge 41 abc. Undergraduate Research and Bachelor's Thesis. *Units to be arranged; first, second, third terms.* Guidance in seeking research opportunities and in formulating a research plan leading to preparation of a bachelor's thesis is available from the GPS option representatives. Graded pass/fail.

Ge 101. Introduction to Geology and Geochemistry. *9 units (3-0-6); first term. Prerequisites: graduate standing or instructor's permission.* A broad, high-level survey of geology and geochemistry with emphasis on quantitative understanding. Historical deduction in the geological and planetary sciences. Plate tectonics as a unifying theory of geology. Igneous and metamorphic processes, structural geology and geomorphology; weathering and sedimentary processes. Nucleosynthesis and chemical history of the solar system; distribution of the elements in the earth; isotopic systems as tracers and clocks; evolution of the biosphere; global geochemical and biogeochemical cycles; geochemical constraints on deep Earth structure. One mandatory overnight field trip, selected laboratory exercises, and problem sets. Instructor: Bucholz.

Ge 102. Introduction to Geophysics. *9 units (3-0-6); second term. Prerequisites: Ma 2, Ph 2, or Ge 108, or equivalents.* An introduction to the physics of the earth. The present internal structure and dynamics of the earth are considered in light of constraints from the gravitational and magnetic fields, seismology, and mineral physics. The fundamentals of wave propagation in earth materials are developed and applied to inferring Earth structure. The earthquake source is described in terms of seismic and geodetic signals. The following are also considered: the contributions that heat-flow, gravity, paleomagnetic, and earthquake mechanism data have made to our understanding of plate tectonics, the driving mechanism of plate tectonics, and the energy sources of mantle convection and the geodynamo. Instructor: Gurnis.

Ge 103. Introduction to the Solar System. *9 units (3-0-6); third term. Prerequisites: instructor's permission.* Formation and evolution of the solar system. Interiors, surfaces, and atmospheres. Orbital dynamics, chaos, and tidal friction. Cratering. Comets and asteroids. Extrasolar planetary systems. Instructor: Brown.

Ge 104. Introduction to Geobiology. *9 units (3-0-6); second term. Prerequisites: instructor's permission.* Lectures about the interaction and coevolution of life and Earth surface environments. We will cover essential concepts and major outstanding questions in the field of geobiology, and introduce common approaches to solving these problems. Topics will include biological fractionation of stable isotopes; history and operation of the carbon and sulfur cycles; evolution of oxygenic photosynthesis; biomineralization; mass extinctions; analyzing biodiversity data; constructing simple mathematical models constrained by isotope mass balance; working with public databases of genetic information; phlyogenetic techniques; microbial and molecular evolution. Instructor: Tejada.

Bi/Ge/ESE 105. Evolution. *12 units (3-4-5);* For course description, see Biology

Ge 106. Introduction to Structural Geology. *9 units (3-0-6); second term. Prerequisites: Ge 11 ab.* Description and origin of main classes of deformational structures. Introduction to continuum mechanics and its application to rock deformation. Interpretation of the record of deformation of the earth's crust and upper mantle on microscopic, mesoscopic, and megascopic scales. Introduction to the tectonics of mountain belts. not offered 2025-26. Instructor: Avouac.

Ay/Ge 107. Introduction to Astronomical Observation. *12 units (2-2-8);* For course description, see Astrophysics

Ge 108. Applications of Physics to the Earth Sciences. *9 units (3-0-6); first term. Prerequisites: Ph 2 and Ma 2 or equivalent.* An intermediate course in the application of the basic principles of classical physics to the earth sciences. Topics will be selected from: mechanics of rotating bodies, the two-body problem, tidal theory, oscillations and normal modes, diffusion and heat transfer, wave propagation, electro- and magneto-statics, Maxwell's equations, and elements of statistical and fluid mechanics. not offered 2025-26. Instructor: Brown.

Ge 109. Oral Presentation. *Units to be arranged;* Practice in the effective organization and the delivery of oral presentation of scientific results before groups. Units and scheduling are done by the individual options. Graded pass/fail. Instructor: Staff.

Ge 110. Introduction to Planetary Mission Formulation and Design. *6 units (3-0-3); third term. Prerequisites: instructor's permission.* An introduction to planetary mission formulation from napkin-sketch-level conceptualization to proposal selection. The course will consist of modules that cover science, systems engineering, instrument design, requirements traceability and data sufficiency, mission implementation, and mission management. Coursework and assignments will include quantitation and design, crafting effective figures, proposal writing, and oral presentations (e.g., mission concept pitches, science/engineering/instrument talks). Instructors: Hofmann, Lunine.

Ge 111. Methods in Field Geophysics. *9 units (6-0-3); third term. Prerequisites: Ge 102, or, be able to opt out with demonstration of prior undergrad coursework in this area.* An introduction to basic methods used for field geophysics (e.g., gravity, resistivity, seismic, surveying and remote sensing). The course will mix classroom and field work in the local area. Instructors: Simons, Zhan.

Ge 112. Sedimentology and Stratigraphy. *12 units (3-5-4); third term. Prerequisites: Ge 11 ab.* Systematic analysis of transport and deposition in sedimentary environments and the resulting composition, texture, and structure of both clastic and chemical sedimentary rocks. The nature and

genesis of sequence architecture of sedimentary basins and cyclic aspects of sedimentary accumulation will be introduced. Covers the formal and practical principles of definition of stratigraphic units, correlation, and the construction of a geologic timescale. Field trip and laboratory exercises. Given in alternate years; offered 2025-26. Instructor: Grotzinger.

Ge 114 a. Mineralogy. *6 units (3-0-3); first term.* Atomic structure, composition, physical properties, occurrence, and identifying characteristics of the major mineral groups. Instructor: Staff.

Ge 114 b. Mineralogy Laboratory. *3 units (0-3-0); first term.* Laboratory work involving the examination, characterization and identification of important minerals by their physical properties. Instructor: Staff.

Ge 115 a. Petrology and Petrography: Igneous Petrology. *9 units (3-3-3); second term. Prerequisites: Ge 114 ab.* Study of the origin, occurrence, tectonic significance and evolution of igneous rocks with emphasis on use of phase equilibria and geochemistry. Given in alternate years; not offered 2025-26. Instructor: Staff.

Ge 115 b. Petrology and Petrography: Metamorphic Petrology. *9 units (3-3-3); third term. Prerequisites: Ge 114 ab.* The mineralogic and chemical composition, occurrence, and classification of metamorphic rocks; interpretation of mineral assemblages in the light of chemical equilibrium and experimental studies. Discussion centers on the use of metamorphic assemblages to understand tectonic, petrologic, and geochemical problems associated with convergent plate boundaries and intrusion of magmas into the continental crust. May be taken before Ge 115 a. not offered 2025-26. Instructor: Eiler.

Ge 115 c. Petrography Laboratory. *6 units (0-4-2); third term. Prerequisites: Ge 114 and either Ge 115 a or Ge 115 b.* Laboratory exercises dealing with examination of igneous and metamorphic rocks and minerals in hand-sample and with the petrographic microscope and other mineral identification methods. not offered 2025-26. Instructor: Staff.

Ge 116. Analytical Techniques Laboratory. *9 units (1-4-4); second term. Prerequisites: Ge 114 a or instructor's permission.* Methods of quantitative laboratory analysis of rocks, minerals, and fluids in geological and planetary sciences. Consists of five intensive two-week modules covering scanning electron microscopy (imaging, energy-dispersive X-ray spectroscopy, electron backscatter diffraction); the electron microprobe (wavelength-dispersive X-ray spectroscopy); X-ray powder diffraction; optical, infrared, and Raman spectroscopy; and plasma source mass spectrometry for elemental and radiogenic isotope analysis. Satisfies the Institute core requirement for an additional introductory laboratory course. Instructors: Asimow, Jackson.

Ge/Ay 117. Bayesian Statistics and Data Analysis. *9 units (3-0-6); second term. Prerequisites: CS 1 or equivalent.* In modern fields of planetary science and astronomy, vast quantities of data are often available to researchers. The challenge is converting this information into meaningful knowledge about the universe. The primary focus of this course is the development of a broad and general tool set that can be applied to the student's own research. We will use case studies from the astrophysical and planetary science literature as our guide as we learn about common pitfalls, explore strategies for data analysis, understand how to select the best model for the task at hand, and learn the importance of properly quantifying and reporting the level of confidence in one's conclusions. not offered 2025-26. Instructor: Knutson.

Ge 119. Geology of the American Southwest. *9 units (3-0-6); third term. Prerequisites: Ge 11 a or Ge 101 or permission of the instructor.* This course is a lecture-based course on the geologic history of the American Southwest (broadly defined as the southern parts of California, Nevada, Utah, and Colorado as well as Arizona and New Mexico). Lectures will cover the geologic history in chronologic order and will highlight the important scientific studies that deciphered the geologic record of the region. Instructor: Bucholz.

Ge 120 a. Introduction to Field Geology. *9 units (1-6-2); third term. Prerequisites: Ge 11 ab, Ge 106 (may be taken concurrently with Ge 106).* A comprehensive introduction to methods of geological field mapping in preparation for summer field camp. Field exercises and associated projects introduce methods of geological mapping, field observations, and graphical techniques in the analysis of geologic maps. Offered every other year. Not offered 2025-26. Instructor: Bucholz.

Ge 120 b. Field Geology: Summer Field Camp. *15 units (0-15-0); summer term. Prerequisites: Ge 120 a or instructor's permission.* Intensive field course in a well-exposed area of the western United States covering techniques of geologic field observation, mapping, analysis, and report preparation. Course is run through an external school with participation of Caltech students arranged via and supported by the GPS division. not offered 2025-26. .

Ge 121 abc. Advanced Field Geology. *12 units (0-9-3); first, second, third terms. Prerequisites: Ge 120 or equivalent, or instructor's permission. For Ge 121a (Lamb): Ge 125 or instructor approval.* Field mapping and supporting laboratory studies in topical problems related to the geology of the southwestern United States. Course provides a breadth of experience in igneous, metamorphic, or sedimentary rocks or geomorphology. Multiple terms of 121 may be taken more than once for credit if taught by different instructors. Instructors: Lamb (a), Staff (b), Grotzinger (c).

Ge 122 abc. Field Geology Seminar. *6 units (1-3-2); first, second, third terms. Prerequisites: Ge 11 ab or Ge 101, or instructor's permission.* Each term, a different field topic will be examined in both seminar and

field format. Relevant readings will be discussed in a weekly class meeting. During the 3-day weekend field trip we will examine field localities relevant to the topic, to permit detailed discussion of the observations. Topic varies every year. Graded pass/fail. not offered 2025-26. Instructor: Staff.

Ge 123. Continental Crust Seminar. *3 units (1-0-2); third term.* A seminar course focusing on a topic related to the continental crust, which will be decided depending on the interest of participating students. Potential topics include arc magmatism, the evolution of the composition of continental crust through time, formation of granites, or specific localities/regions that help shape our understanding of continental crust generation. The course will comprise weekly student-lead discussion of scientific journal articles. not offered 2025-26. Instructor: Bucholz.

Ge 124 a. Paleomagnetism and Magnetostratigraphy. *6 units (0-0-6); third term.* Application of paleomagnetism to the solution of problems in stratigraphic correlation and to the construction of a high-precision geological timescale. A field trip to the southwest United States or Mexico to study the physical stratigraphy and magnetic zonation, followed by lab analysis. Not offered 2025-26. Instructor: Kirschvink.

Ge 124 b. Paleomagnetism and Magnetostratigraphy. *9 units (3-3-3); third term. Prerequisites: Ge 11 ab.* The principles of rock magnetism and physical stratigraphy; emphasis on the detailed application of paleomagnetic techniques to the determination of the history of the geomagnetic field. Not offered 2025-26. Instructor: Kirschvink.

Ge/ESE 125. Earth's Landscapes. *12 units (3-5-4); first term. Prerequisites: Ge 11 a or instructor's permission.* Introduction to the processes that shape the surface of Earth through erosion, transport and deposition of sediment. Topics include soil formation, landslides and debris flows, catchment hydrology, river hydraulics and sediment transport, river and floodplain morphology, and glacier flow and erosion. The course also explores associated geologic hazards; landscape sustainability such as coastal land loss and river restoration; interplay with climate, tectonics and the carbon cycle; and landscapes on other rocky planets. Local field trips and laboratory exercises facilitate two projects on quantitative analysis of rivers and landslides in the Los Angeles area. not offered 2025-26. . Instructor: Lamb.

Ge 126. Topics in Earth Surface Processes. *6 units (2-0-4); second term.* A seminar-style course focusing on a specific theme within geomorphology and sedimentology depending on student interest. Potential themes could include river response to climate change, bedrock erosion in tectonically active mountain belts, or delta evolution on Earth and Mars. The course will consist of student-led discussions centered on readings from peer-reviewed literature. Instructor: Lamb.

Ge/Ch 127. Nuclear Chemistry. *9 units (3-0-6); third term. Prerequisites: instructor's permission.* A survey course in the properties of nuclei, and in atomic phenomena associated with nuclear-particle detection. Topics include rates of production and decay of radioactive nuclei; interaction of radiation with matter; nuclear masses, shapes, spins, and moments; modes of radioactive decay; nuclear fission and energy generation. not offered 2025-26. Instructor: Burnett.

Ge/Ch 128. Cosmochemistry. *9 units (3-0-6); second term. Prerequisites: instructor's permission.* Examination of the chemistry of the interstellar medium, of protostellar nebulae, and of primitive solar-system objects with a view toward establishing the relationship of the chemical evolution of atoms in the interstellar radiation field to complex molecules and aggregates in the early solar system that may contribute to habitability. Emphasis will be placed on identifying the physical conditions in various objects, timescales for physical and chemical change, chemical processes leading to change, observational constraints, and various models that attempt to describe the chemical state and history of cosmological objects in general and the early solar system in particular. Given in alternate years; not offered 2025-26. Instructor: Blake.

ESE/Ge 129. Soil Systems Microbiology. *9 units (3-3-3);* For course description, see Environmental Science & Engineering

Ge 131. Planetary Structure and Evolution. *9 units (3-0-6); third term. Prerequisites: instructor's permission.* A critical assessment of the physical and chemical processes that influence the initial condition, evolution, and current state of planets, including our planet and planetary satellites. Topics to be covered include a short survey of condensed-matter physics as it applies to planetary interiors, remote sensing of planetary interiors, planetary modeling, core formation, physics of ongoing differentiation, the role of mantle convection in thermal evolution, and generation of planetary magnetic fields. Instructor: Fuller.

Ge/Ay 132. Atomic and Molecular Processes in Astronomy and Planetary Sciences. *9 units (3-0-6); second term. Prerequisites: instructor's permission.* Fundamental aspects of atomic and molecular spectra that enable one to infer physical conditions in astronomical, planetary, and terrestrial environments. Topics will include the structure and spectra of atoms, molecules, and solids; transition probabilities; photoionization and recombination; collisional processes; gas-phase chemical reactions; and isotopic fractionation. Each topic will be illustrated with applications in astronomy and planetary sciences, ranging from planetary atmospheres and dense interstellar clouds to the early universe. Given in alternate years; not offered 2025-26. Instructor: Blake.

Ge/Ay 133. The Formation and Evolution of Planetary Systems. *9 units (3-0-6); first term.* Review current theoretical ideas and observations

pertaining to the formation and evolution of planetary systems. Topics to be covered include low-mass star formation, the protoplanetary disk, accretion and condensation in the solar nebula, the formation of gas giants, meteorites, the outer solar system, giant impacts, extrasolar planetary systems. Instructor: Batygin.

Ge 136 abc. Regional Field Geology of the Southwestern United States. *3 units (1-0-2); first, second, or third terms, by announcement. Prerequisites: Ge 11 ab or Ge 101, or instructor's permission.* Includes approximately three days of weekend field trips into areas displaying highly varied geology. Each student is assigned the major responsibility of being the resident expert on a pertinent subject for each trip. Graded pass/fail. Instructor: Kirschvink.

Ge/Ay 137. Planetary Physics. *9 units (3-0-6); second term. Prerequisites: Ph 106 abc, ACM 95/100 ab.* A quantitative review of dynamical processes that characterize long-term evolution of planetary systems. An understanding of orbit-orbit resonances, spin-orbit resonances, secular exchange of angular momentum and the onset of chaos will be developed within the framework of Hamiltonian perturbation theory. Additionally, dissipative effects associated with tidal and planet-disk interactions will be considered. Instructor: Batygin.

Ge/ESE 139. Introduction to Atmospheric Radiation. *9 units (3-0-6); second term. Prerequisites: Ma 2, Ph 2, or instructor's permission.* The basic physics of absorption and scattering of light by molecules, aerosols, and clouds. Theory of radiative transfer. Band models, correlated-k distributions and other approximate methods. Solar insolation, thermal emission, heating rates and radiances. Applications to Earth, Planets and Exoplanets. Not offered 2025-26. Instructor: Yung.

Ge 140 a. Stable Isotope Geochemistry. *9 units (3-0-6); second term.* An introduction to the principles and applications of stable isotope systems to earth science, emphasizing the physical, chemical and biological processes responsible for isotopic fractionation, and their underlying chemical-physics principles. Topics include the kinetic theory of gases and related isotopic fractionations, relevant subjects in quantum mechanics and statistical thermodynamics, equations of motion of charged particles in electrical and magnetic fields (the basis of mass spectrometry), the photochemistry of isotopic species, and applications to the earth, environmental and planetary sciences. Taught in odd years; alternates with Ge 140 b. Instructor: Eiler.

Ge 140 b. Radiogenic Isotope Geochemistry. *9 units (3-0-6); second term.* An introduction to the principles and applications of radiogenic isotope systems in earth science, with emphasis on the applications of these systems, from dating to forensic. Topics to be covered include nucleosynthesis, radioactive decay phenomena, geochronology, geochronometry, isotopes as tracers of solar system and planetary evolution, extinct radioactivities, cosmogenic isotopes and forensic geochemistry. Taught in even years; alternates with Ge 140 a. Offered

2025-26. Instructor: Tissot.

Ge/ESE 140 c. Stable Isotope Biogeochemistry. *9 units (3-0-6); third term. Prerequisites: Ge 140 a or equivalent.* An introduction to the use of stable isotopes in biogeochemistry, intended to give interested students the necessary background to understand applications in a variety of fields, from modern carbon cycling to microbial ecology to records of Ancient Earth. Topics include the principles of isotope distribution in reaction networks; isotope effects in enzyme-mediated reactions, and in metabolism and biosynthesis; characteristic fractionations accompanying carbon, nitrogen, and sulfur cycling; and applications of stable isotopes in the biogeosciences. Offered 2025-26. Instructor: Sessions.

Ge 141. Isotope Cosmochemistry. *9 units (3-0-6); first term. Prerequisites: Instructor's permission.* An introduction to the study of the origin, abundances and distribution of the elements and their isotopes in the Universe, with emphasis on the isotopic constraints into the conditions, events and processes that shaped our Solar System. Topics to be covered include: cosmology and the age of the Universe, the age of the Milky Way and the duration of nucleosynthesis, the fundamentals of isotopic fractionations, the key roles of isotopic anomalies in understanding Solar System dynamics, early Solar System chronology from short- and long-lived nuclei, chondritic meteorite components as clues to solar nebula and asteroid evolution, as well as planetary formation and chronology (e.g., Moon, Mars, Earth). not offered 2025-26. Instructor: Tissot.

ESE/Ge/Ch 142. Aquatic Chemistry of Natural Waters. *9 units (3-0-6);* For course description, see Environmental Science & Engineering

Ge/ESE 143. Organic Geochemistry. *9 units (3-2-4); third term. Prerequisites: Ch 41 a or equivalent.* Main topics include the analysis, properties, sources, and cycling of natural organic materials in the environment, from their production in living organisms to burial and decomposition in sediments and preservation in the rock record. Specific topics include analytical methods for organic geochemistry, lipid structure and biochemistry, composition of organic matter, factors controlling organic preservation, organic climate and CO2 proxies, diagenesis and catagenesis, and biomarkers for ancient life. A laboratory component (three evening labs) teaches the extraction and analysis of modern and ancient organic biomarkers by GC/MS. Class includes a mandatory one-day (weekend) field trip to observe the Monterey Formation. not offered 2025-26. Instructor: Sessions.

Ge 145. Isotope-Ratio Mass Spectrometry. *9 units (1-4-4); first term.* This class provides a hands-on introduction to the construction and operating principles of instrumentation used for isotope-ratio mass spectrometry. The class is structured as a 1-hour lecture plus 4-hour lab each week examining the major subsystems of an IRMS, including vacuum systems, ionization source, mass analyzer, and detector.

Laboratories involve hands-on deconstruction and re-assembly of a retired IRMS instrument to examine its components. Course is limited to 6 students at the discretion of the instructor, with preference given to graduate students using this instrumentation in their research. Taught in odd years; not offered 2025-26. Instructor: Sessions.

ME/CE/Ge/ESE 146. Computational Methods for Flow in Porous Media. *9 units (3-0-6);* For course description, see Mechanical Engineering

Ge/Bi/BE/CNS/ESE 147. Challenges and Opportunities in Quantitative Ecology. *6 units (6-0-0); third term.* Ecosystems are defined by dynamical interactions between groups of organisms, the communities they constitute, and the physical and chemical conditions and processes occurring in the environment. These dynamics are complex and multiscale across both length and time. This course will explore quantitative approaches that observe, measure, model, and monitor ecosystems and the services that they provide society-and the emerging opportunities that could employ these approaches to improve and strengthen global sustainability when it comes to our own ecology. This course will feature lectures each week from different members of the Caltech faculty working on ecological problems from different angles in order to illustrate how fresh insights can emerge by drawing on diverse ways-of-knowing. not offered 2025-26. Instructors: Fischer, Tejada.

Ge/ESE 149. Marine Geochemistry. *9 units (3-0-6); second term. Prerequisites: ESE 102.* Introduction to chemical oceanography and sediment geochemistry. We will address the question "Why is the ocean salty?" by examining the processes that determine the major, minor, and trace element distributions of seawater and ocean sediments. Topics include river and estuarine chemistry, air/sea exchange, nutrient uptake by the biota, radioactive tracers, redox processes in the water column and sediments, carbonate chemistry, and ventilation. Given in alternate years; offered 2025-26. Instructor: Adkins.

Ge/ESE 150. Planetary Atmospheres. *9 units (3-0-6); third term. Prerequisites: Ch 1, Ma 2, Ph 2, or equivalents.* A broad survey of the formation, evolution, and present-day properties of planetary atmospheres, drawing examples from both the solar system and extrasolar planet literature. We will cover topics including energy balance, radiative transfer, chemistry, cloud formation, dynamics, and escape. The goal of this class is to provide an overview of key concepts relevant to planetary atmospheres that can serve as a foundation for future coursework or research in this area. Instructor: Knutson.

Ge 151. Planetary Surfaces. *9 units (3-3-3); second term.* We will review the mechanisms responsible for the formation and modification of the surfaces of solar system bodies, studying both composition and physical processes. Topics include exogenous processes (impact cratering, space weathering) and endogenous processes (tectonic, volcanic, weathering, fluvial, aeolian, and periglacial) that shape the surfaces of

planets. Lectures, occasional labs, and one required field trip. Instructor: de Kleer.

Ge/ESE 154. Readings in Paleoclimate. *3 units (1-0-2); second term. Prerequisites: instructor's permission.* Lectures and readings in areas of current interest in paleoceanography and paleoclimate. Instructor: Adkins.

Ge/ESE 155. Paleoceanography. *9 units (3-0-6); second term. Prerequisites: ESE 102.* Evaluation of the data and models that make up our current understanding of past climates. Emphasis will be placed on a historical introduction to the study of the past ten thousand to a few hundred thousand years, with some consideration of longer timescales. Evidence from marine and terrestrial sediments, ice cores, corals, and speleothems will be used to address the mechanisms behind natural climate variability. Models of this variability will be evaluated in light of the data. Topics will include sea level and ice volume, surface temperature evolution, atmospheric composition, deep ocean circulation, tropical climate, ENSO variability, and terrestrial/ocean linkages. not offered 2025-26. Instructor: Adkins.

Ge 156. Topics in Planetary Surfaces. *6 units (3-0-3);* Offered by announcement only. Reading about and discussion of current understanding of the surface of a selected terrestrial planet, major satellite, or asteroid. Important "classic" papers will be reviewed, relative to the data that are being returned from recent and current missions. May be repeated for credit.

Ge/EE/ESE 157 c. Remote Sensing for Environmental and Geological Applications. *9 units (3-3-3); third term.* Analysis of electromagnetic radiation at visible, infrared, and radio wavelengths for interpretation of the physical and chemical characteristics of the surfaces of Earth and other planets. Topics: interaction of light with materials, spectroscopy of minerals and vegetation, atmospheric removal, image analysis, classification, and multi-temporal studies. This course does not require but is complementary to EE 157 ab with emphasis on applications for geological and environmental problems, using data acquired from airborne and orbiting remote sensing platforms. Students will work with digital remote sensing datasets in the laboratory and there will be one field trip. Not offered 2025-26. Instructor: Staff.

Ge/Ay 159. Astrobiology. *9 units (3-0-6); second term.* We approach the age-old questions "Why are we here?" and "Are we alone?" by covering topics in cosmology, the origins of life, planetary habitability, the detection of biosignatures, the search for extraterrestrial intelligence, and humanity's future in space. Specific topics include: the emergence of life at hydrothermal vents; the habitable zone and the Gaia hypothesis; the search for ancient habitable environments on Mars; icy satellites like Europa, Enceladus, and Titan as astrobiological prospects; and the hunt for atmospheric biosignatures on exoplanets. Instructor: Yung.

Ae/Ge/ME 160 ab. Continuum Mechanics of Fluids and Solids. *9 units (3-0-6);* For course description, see Aerospace

Ge 161. Plate Tectonics. *9 units (3-0-6); first term. Prerequisites: Ge 11 ab or equivalent.* Geophysical and geological observations related to plate tectonic theory. Instantaneous and finite motion of rigid plates on a sphere; marine magnetic and paleomagnetic measurements; seismicity and tectonics of plate boundaries; reference frames and absolute plate motions. Interpretations of geologic data in the context of plate tectonics; plate tectonic evolution of the ocean basins. Instructor: Stock.

Ge 162. Seismology. *9 units (3-0-6); second term. Prerequisites: ACM 95/100 ab or equivalent.* Review of concepts in classical seismology. Topics to be covered: basic theories of wave propagation in the earth, instrumentation, Earth's structure and tomography, theory of the seismic source, physics of earthquakes, and seismic risk. Emphasis will be placed on how quantitative mathematical and physical methods are used to understand complex natural processes, such as earthquakes. Instructor: Zhan.

Ge 163. Geodynamics. *9 units (3-0-6); third term. Prerequisites: Ae/Ge/ME 160 ab.* Quantitative introduction to the dynamics of the earth, including core, mantle, lithosphere, and crust. Mechanical models are developed for each of these regions and compared to a variety of data sets. Potential theory applied to the gravitational and geomagnetic fields. Special attention is given to the dynamics of plate tectonics and the earthquake cycle. not offered 2025-26. Instructor: Gurnis.

Ge 164. Mineral Physics. *9 units (3-0-6); second term. Prerequisites: Ge 11 ad or equivalent, or instructor's permission.* Introduction to the mineral physics of Earth's interior. Topics covered: mineralogy and phase transitions at high pressures and temperatures; elasticity and equations of state; vibrational, electronic, and transport properties; application of mineral physics data to Earth and planetary interiors. Taught every other year; offered 2025-26. Instructor: Jackson.

Ge 165. Geophysical Inverse Problems. *9 units (3-0-6); second term. Prerequisites: basic linear algebra and Fourier transforms.* Fundamentals of inverse theory and data analysis, with applications to geophysical problems. Linear and nonlinear inverse problems; generalized inverse and singular value decomposition; resolution; regularization; discrete and continuous representations; basics of signal processing including Fourier methods, correlation, convolution, and filtering. Offered every other year. Not offered 2025-26. . Instructor: Ross.

Ge 166. Machine Learning in Geophysics. *9 units (3-0-6); first term. Prerequisites: Ge 117 or Ge 165; or equivalent, with instructor's permission.* Introduction to deep learning, with applications to modern geophysical research. Supervised and unsupervised learning with spatiotemporal data; architecture design; deep generative models; solving partial differential equations and operator learning;

physics-informed deep learning. The course will address data requirements, current limitations, and the role of machine learning in the future of geophysics. Instructor: Ross.

Ge 167. Tectonic Geodesy. *9 units (3-0-6); second term. Prerequisites: a working knowledge of unix/linux or equivalent, linear algebra, and coursework in geophysics.* An introduction to the use of modern geodetic observations (e.g., GPS and InSAR) to constrain crustal deformation models. Secular velocity fields, coseismic and time-dependent processes; volcano deformation and seasonal loading phenomena. Basic inverse approaches for parameter estimation and basic temporal filtering algorithms. Instructor: Simons.

Ge 169 abcd. Readings in Geophysics. *6 units (3-0-3); first, second, third, summer terms.* Reading courses are offered to teach students to read critically the work of others and to broaden their knowledge about specific topics. Each student will be required to write a short summary of each paper that summarizes the main goals of the paper, to give an assessment of how well the author achieved those goals, and to point out related issues not discussed in the paper. Each student will be expected to lead the discussion on one or more papers. The leader will summarize the discussion on the paper(s) in writing. A list of topics offered each year will be posted on the Web. Individual terms may be taken for credit multiple times without regard to sequence. Instructor: Staff.

ESE/Ge/Ch 171. Atmospheric Chemistry I. *9 units (3-0-6);* For course description, see Environmental Science & Engineering

ME/CE/Ge 174. Mechanics of Rocks. *9 units (3-0-6);* For course description, see Mechanical Engineering

Ge 177. Active Tectonics. *12 units (3-3-6); third term. Prerequisites: Ge 112 and Ge 106 or equivalent.* Introduction to techniques for identifying and quantifying active tectonic processes. Geomorphology, stratigraphy, structural geology, and geodesy applied to the study of active faults and folds in a variety of tectonic settings. Relation of seismicity and geodetic measurements to geologic structure and active tectonics processes. Review of case studies of selected earthquakes. Given in alternate years; offered 2025-26. Instructor: Avouac.

Ge/ESE/Bi 178. Microbial Ecology. *9 units (3-2-4); second term. Prerequisites: either ESE/Bi 166 or ESE/Bi 168 recommended.* Structural, phylogenetic, and metabolic diversity of microorganisms in nature. The course explores microbial interactions, relationships between diversity and physiology in modern and ancient environments, and influence of microbial community structure on biogeochemical cycles. Introduction to ecological principles and molecular approaches used in microbial ecology and geobiological investigations. Given in alternate years; not offered 2025-26. Instructor: Orphan.

ESE/Ge/Bi/ChE 184. Computational Tools for Decoding Microbial Ecosystems. *9 units (3-0-6);* For course description, see Environmental Science & Engineering

Ge 190. The Nature and Evolution of the Earth. *Units to be arranged; offered by announcement only.* Advanced-level discussions of problems of current interest in the earth sciences. Students may enroll for any or all terms of this course without regard to sequence. Instructor: Staff.

Ge 191. Special Topics in Geochemistry. *Units to be arranged; offered by announcement only.* Advanced-level discussions of problems of current interest in geochemistry. Students may enroll for any or all terms of this course without regard to sequence. Instructor: Staff.

Ge 192. Special Topics in the Geological Sciences. *Units to be arranged; first term.* Advanced-level discussions of problems of current interest in the geological sciences. Students may enroll for any or all terms of this course without regard to sequence. Instructor: Venditti.

Ge 193. Special Topics in Geophysics. *Units to be arranged; second term.* Advanced-level discussions of problems of current interest in geophysics. Students may enroll for any or all terms of this course without regard to sequence. Instructor: Lecampion.

Ge 194. Special Topics in Planetary Sciences. *Units to be arranged; offered by announcement only.* Advanced-level discussions of problems of current interest in planetary sciences. Students may enroll for any or all terms of this course without regard to sequence. Instructor: Staff.

Ge 195. Special Topics in Field Geology. *Units to be arranged; first term.* Field experiences in different geological settings. Supporting lectures will usually occur before and during the field experience. This course will be scheduled only when special opportunities arise. Class may be taken more than once. Instructor: Behr.

Ge 196. Special Topics in Atmospheres and Oceans. *Units to be arrange; offered by announcement only.* Advanced-level discussions of problems of current interest in atmospheric and ocean sciences. Instructor: Staff.

Ge 197. Special Topics in Geobiology: Oxygen. *6 units (2-0-4);* Abundant molecular oxygen is a defining feature of the biology and geochemistry at the surface of our planet, but the geological record shows us that this was not always the case. This course will combine lectures with advanced-level discussions of selected literature and project-based work focused on the modern oxygen cycle, current knowledge of the history of atmospheric oxygen, and new ideas and constraints on the evolution of aerobic metabolisms. Offered by announcement only. Instructor: Staff.

Ay/Ge 198. Special Topics in the Planetary Sciences. *6 units (2-0-4);* For course description, see Astrophysics

Ge 211. Applied Geophysics II. *Units to be arranged; first term. Prerequisites: instructor's permission.* Intensive geophysical field experience in either marine or continental settings. Marine option will include participation in a student training cruise, with several weeks aboard a geophysical research vessel, conducting geophysical measurements (multibeam bathymetry, gravity, magnetics, and/or seismics), and processing and interpreting the data. Supporting lectures and problem sets on the theoretical basis of the relevant geophysical techniques and the tectonic background of the survey area will occur before and during the training cruise. The course might be offered in a similar format in other isolated situations. The course will be scheduled only when opportunities arise and this usually means that only six months' notice can be given. Auditing not permitted. Class may be taken more than once. Not offered 2025-26. Instructor: Staff.

Ge 212. Thermodynamics of Geological Systems. *9 units (3-0-6); first term. Prerequisites: Either Ch 21 abc, Ge 115 a, or equivalents.* Chemical thermodynamics as applied to geological and geochemical problems. Classical thermodynamics, including stability criteria, homogeneous and heterogeneous equilibria, equilibria subject to generalized constraints, equations of state, ideal and non-ideal solutions, redox systems, and electrolyte conventions. Brief discussion of statistical foundations and an introduction to the thermodynamics of irreversible processes. Given in alternate years; not offered 2025-26. Instructor: Asimow.

Ge 214. Spectroscopy of Minerals. *9 units (3-0-6); third term. Prerequisites: Ge 114 a, Ch 21 ab, or instructor's permission.* An overview of the interaction of minerals with electromagnetic radiation from gamma rays to microwaves. Particular emphasis is placed on visible, infrared, Raman, and Mössbauer spectroscopies as applied to mineralogical problems such as phase identification, chemical analysis, site populations, and origin of color and pleochroism. Given in alternate years; not offered 2025-26. Instructor: Rossman.

Ge 215. Topics in Advanced Petrology. *9 units (3-0-6); first term. Prerequisites: Ge 115 ab or instructor's permission.* Lectures, readings, seminars, and/or laboratory studies in igneous or metamorphic petrology, paragenesis, and petrogenesis. The course may cover experimental, computational, or analytical methods. Format and content are flexible according to the needs of the students. Given in alternate years; not offered 2025-26. Instructor: Asimow.

Ge 217. Radiogenic Isotopes Seminar. *6 units (3-0-3); third term. Prerequisites: Ge 140 b or permission of instructor.* The course deals with advanced topics in radiogenic isotope geochemistry and builds on Ge 140 b, addressing unconventional applications of radioisotopes as well as treating several conventional radiogenic systems in more detail. Topics to be covered will be guided by class interests. Given in alternate

years; offered 2025-26. Instructor: Farley.

Ge 218. Stable Isotopes Seminar. *6 units (3-0-3); second term. Prerequisites: Ge 140 or permission of instructor.* The course deals with advanced topics in stable isotope geochemistry and builds on Ge 140. The course will explore in depth the theory and applications of a subject in stable isotope geochemistry, selected by consensus of the enrolled students at or before the beginning of term. Example subjects could include: stable isotope thermometry; paleoclimate studies; paleoaltimetry; the early solar system; terrestrial weathering; photochemistry; or biosynthetic fractionations. The class will read and discuss classic papers in that subject area, supplemented with instructor lectures and broader background reading. All participants will lead discussions of papers and present one lecture on a relevant subject. Given in alternate years; offered 2025-26. Instructor: Eiler.

Ge 219. Non-traditional Isotopes Seminar. *6 units (2-0-4); third term. Prerequisites: Ge 140 a or b, or permission of instructor.* The course deals with advanced topics in stable and radiogenic isotope geo-/cosmochemistry and builds on Ge 140 a and b, with emphasis on non-traditional isotope systems (Mg, Fe, Ti, Mo, U, etc.). Starting with close examination of seminal papers, each topic will build up to a discussion of the remaining outstanding questions. Topics to be covered will be guided by class interests. Example subjects could include: the early solar system, nucleosynthetic anomalies, the early Earth, planetary differentiation, paleoredox reconstructions, medical use of stable isotopes. Given sufficient enrollment (~5 or more), course format will follow a "Role playing paper-reading" style (https://colinraffel.com/blog/role-playing-seminar.html). Grades will include participation, intellectual contribution to updating the content of the periodic table of stable isotopes, and the writing by the whole class of a scientific review/original paper (with the goal of submitting it for publication). Instructor: Tissot.

Ae/AM/ME/Ge 225. Special Topics in Solid Mechanics. *Units to be arranged;* For course description, see Aerospace

Ge/Bi 244. Paleobiology Seminar. *6 units (3-0-3); first term.* Critical reviews and discussion of classic investigations and current research in paleoecology, evolution, and biogeochemistry. Instructor: Tejada.

Ge/Bi/ESE 246. Molecular Geobiology Seminar. *6 units (2-0-4); first term.* Critical reviews and discussion of classic papers and current research in microbiology and geomicrobiology. As the topics will vary from year to year, it may be taken multiple times. Not offered 2025-26. Instructor: Orphan.

Ge/ESE/Bi 248. Environmental Justice. *6 units (2-0-4); first term.* This seminar course will explore and discuss the unique intersection of environmental racism, environmental justice, and academia. Course material will primarily feature readings and videos on a case study-like

basis and focus on bringing conversations typically had in humanities, social sciences and activism to the bio and geosciences. Topics will center around two primary approaches: an "outward-facing" component that looks at environmental racism through the lens of various activisms, and an "inward-facing" component addressing the biases/malpractices broadly employed in the biological and geosciences, as well as the apparent moral dilemmas of decisions involving multiple stakeholders. Out of class work will largely be based on assigned readings, some multimedia presentations, and occasional writings and thought exercises. This course is taught concurrently with Hum 61 and can only be taken once, as Ge/ESE/Bi 248 or Hum 61. Instructor: Orphan.

Ge/Bi/ESE/CE 249. Stable Isotopes: Ecological and Environmental Applications. *9 units (3-3-3); first term.* An introduction to various stable isotopes systems and their extensive applications in ecological, evolutionary, and environmental research. Topics covered include uses of stable isotopes in plant and animal ecology, hydrological systems, reconstruction of past climates, cultural development, and forensics. The class includes lectures and occasional lab sessions. Instructor: Tejada.

Ge 261. Advanced Seismology. *9 units (3-0-6); third term.* Continuation of Ge 162 with special emphasis on particular complex problems; includes generalizations of analytical methods to handle nonplanar structures and methods of interfacing numerical-analytical codes in two and three dimensions; construction of Earth models using tomographic methods and synthetics. Requires a class project. Instructor: Zhan.

Ge 263. Computational Geophysics. *9 units (3-0-6); first term. Prerequisites: introductory class in geophysics, class in partial differential equations, some programming experience.* Finite-difference, pseudo-spectral, finite-element, and spectral-element methods will be presented and applied to a number of geophysical problems including heat flow, deformation, and wave propagation. Students will program simple versions of methods. Given in alternate years; not offered 2025-26. Instructor: Gurnis.

Ae/AM/CE/ME/Ge 265 ab. Static and Dynamic Failure of Brittle Solids and Interfaces, from the Micro to the Mega. *9 units (3-0-6);* For course description, see Aerospace

ME/Ge/Ae 266 ab. Fracture and Frictional Faulting. *9 units (3-0-6);* For course description, see Mechanical Engineering

Ge 271. Dynamics of Seismicity. *9 units (3-0-6); second term.* A comprehensive introduction to seismicity of the Earth. Topics covered: Empirical laws for seismicity; spatial and temporal evolution of earthquake sequences; earthquake location algorithms; seismicity in crustal fault zones, subduction zones, creeping faults, volcanoes, and intraplate regions; earthquake triggering; induced seismicity; tectonic tremor and low-frequency earthquakes. Requires a class project. Instructor: Ross.

Ge 277. Active Tectonics Seminar. *6 units (2-0-4); second term.* Discussion of key issues in active tectonics based on a review of the literature. The topic of the seminar is adjusted every year based on students' interest and recent literature. Given in alternate years; not offered 2025-26. Instructor: Avouac.

Ge/ESE 298. Mentoring and Outreach. *Units to be arranged, up to 12 units per year;* In consultation with a faculty advisor and the Caltech Center for Teaching, Learning, and Outreach, students may obtain credit for engaging in volunteer efforts to promote public understanding of science; to mentor and tutor young people and underserved populations; or to otherwise contribute to the diversity, equity, and inclusiveness of the scientific enterprise. Students may petition their option representative (graduate students) or academic advisor (undergraduate students) if they seek credits beyond the 12-unit limit. Instructor: Staff.

Ge 299. Thesis Research. *;* Original investigation, designed to give training in methods of research, to serve as theses for higher degrees, and to yield contributions to scientific knowledge.

HISTORY

Hum/H 1. The Classical and Medieval Worlds. *9 units (3-0-6); first, second terms.* This course will survey the evolution of Mediterranean and European civilization from antiquity through the end of the Middle Ages. It will emphasize the reading and discussion of primary sources, especially but not exclusively literary works, against the backdrop of the broad historical narrative of the periods. The readings will present students with the essential characteristics of various ancient and medieval societies and give students access to those societies' cultural assumptions and perceptions of change. Not offered 2025-26.

Hum/H 2. Freedom Dreams: African American Visions of Liberation Since Emancipation. *9 units (3-0-6); first term.* Over the course of their history in the United States, African Americans have advanced various visions of liberation and strategies for attaining it. This course will examine how African Americans have conceptualized and sought to realize their freedom dreams since the end of chattel slavery. We will focus, in particular, on visions of freedom considered radical or utopian, both in their contemporary moment and in our present. Investigating how African Americans have imagined freer lives beyond their own localities, beyond U.S. borders, and even beyond Earth, our topics of discussion in the course may include emigration movements, black communism, pan-Africanism, black feminism, cults, Afrofuturism, hip hop culture, and abolitionism. Not offered 2025-26.

Hum/H 3. The United States in the Twentieth Century. *9 units (3-0-6); first term.* Designed to introduce students to the academic study of

history, this course examines key issues and events that shaped the political, social, and cultural history of the United States in the Twentieth Century. Through a wide variety of historical sources-including primary documents, fiction, and music-students will explore issues such as popular culture, immigration and labor, the civil rights movement, political realignment, and American intervention abroad. Not offered 2025-26.

Hum/H 5. The History of the Chinese Empire. *9 units (3-0-6); first, second terms.* This class will explore several facets of how the concept of empire and its historical formation in China was defined, portrayed, and developed over time. It offers students a chance to reflect on the interaction of event, record, and remembrance as these components combine in the creation and contestation of history. This course will particularly emphasize how the making, writing, and remembering of history responds to the advent of different regimes of legitimacy in order to give students a new perspective on the relationship between action, authorship, and interpretation in history. Not offered 2025-26.

Hum/H 6. Civilization, Science, and Archaeology: The Development of Science from Babylon through the Renaissance. *9 units (3-0-6); first term.* Connections in antiquity between astrology and astronomy, early theories of light, Islamic science, new concepts of knowledge during the European Middle Ages and Renaissance, the early laboratory, the development of linear perspective, the origins of the Copernican and Keplerian systems of astronomy, and the science of Galileo. Instructor: Buchwald.

Hum/H 7. Civilization, Science, and Archaeology: The Nature of Religious Belief in Ancient Egypt, Mesopotamia, and Israel. *9 units (3-0-6); second, third terms.* The civilizations of Egypt and Mesopotamia gave rise to complex forms of religious practices connected to the social order, moral behavior, and the afterlife. The course examines the origins of concepts of moral death and of sin as a violation of cosmic order in antiquity, the nature of polytheism, and the manner in which monotheism arose out of it. In addition to historical analyses the course includes readings by anthropologists who have studied cult structures as well as contemporary theories by evolutionary psychologists. Not offered 2025-26.

Hum/H 8. Civilization, Science, and Archaeology: Before Greece: The Origins of Civilization in Mesopotamia. *9 units (3-0-6); second, third terms.* This course will introduce students to the early development of civilization in Mesopotamia and Egypt from 4000 B.C.E. through 1000 B.C.E. Origins of agriculture and writing, the evolution of the city, and the structures of the Mesopotamian economy and social order will be discussed. Comparison with contemporary developments in Egypt during the Old and Middle Kingdoms may include a reading of Gilgamesh from 3000 B.C.E. and of the Egyptian Tale of Sinuhe. The course concludes with a discussion of life during the late Bronze Age. Focus will be on life as it was lived and experienced by many groups in

pre-classical antiquity rather than on kings and dynasties. Not offered 2025-26.

Hum/H 9. Europe Transformed. *9 units (3-0-6); third term.* Will introduce students to major aspects of the politics and culture of modernity that have profoundly transformed Western society and consciousness from the French Revolution to the contemporary era. A variety of historical, literary, and artistic works will be used to illuminate major social, intellectual, and cultural movements. The focus will be on significant and wide-ranging historical change (e.g., the industrial revolution, imperialism, socialism, fascism); on cultural innovation (e.g., modernism, impressionism, cubism); and on the work of significant thinkers. Not offered 2025-26.

Hum/H 10. Medieval Europe: The Problem of Violence. *9 units (3-0-6); first, second terms.* This course will explore how people understood violence in Europe between ca. 500 and ca. 1400 AD. It will focus on the various norms that governed the use of violence in a period when the right of free people to carry and use weapons was considered self-evident. Working through primary sources, students will explore the relationship between violence and vengeance, the law, central authority and public order, religion, emotions, public ritual, and economics. As they go along students will consider whether violence can coexist with or even promote stable, ordered societies, or whether it by definition creates disorder. Instructor: Brown.

Hum/H 11. Love and Death: Using Demography to Study the History of Europe from 1700. *9 units (3-0-6); first, third terms.* Demographic events-births, marriages, deaths-have always been highly responsive to changes in the local environment. Decisions about when to marry, how many children to have, or what kind of household to live in have always been closely correlated to decisions people take in other areas of their lives and, as a result, can tell us a great deal about the economic, social, and cultural worlds people inhabit. This course examines differences in demographic trends in Europe across space and time, from 1700 to the present, as well as existing explanations for these differences, including political economic factors, social and cultural norms, biology and disease environments. Some topics include: the demographic effects of war, industrialization, and urbanization; changes related to the emergence of reliable contraceptive technologies; changes related to the expansion of economic opportunities for women; the effects of government policies on demographic decisions. Not offered 2025-26.

Hum/H 12. Social Theory. *9 units (3-0-6); first term.* This course introduces students to both canonical and non-canonical theories of society. From the formative debates over the role of the state in human affairs in early modern Europe to radical interpretations of social good in the twentieth century, students will be exposed to competing theories of society and their implications in the political, the economic, the emotional, and the scientific realms. By the end of the quarter, students will be able to link contemporary notions of individuality, agency,

rationality, morality, and ethics to divergent discourses in the history of social theory. Not offered 2025-26.

Hum/H 13. Brave New Worlds: Race, Human Rights and the Age of Discovery. *9 units (3-0-6); second, third term.* This course traces the origins of modern racism and, perhaps surprisingly, of human rights advocacy itself, to a seminal moment in global history sometimes called the Age of Discovery. At this time, two small European kingdoms, Spain and Portugal, first conducted trade and conquest in Atlantic Africa, the Americas, and the Indian and Pacific Oceans, forging the world's first truly global empires. We study the legacy of racism and humanitarianism in eye-witness accounts, maps, images and other materials attesting to Spain's seminal encounters with the Americas. Instructor: Wey-Gomez.

Hum/H/HPS 14. Race, Science, and Medicine in U.S. History. *9 units (3-0-6); second term.* This course will explore how natural philosophers and scientists have defined, used, and sometimes challenged ideas about race from the eighteenth century to today. Using a range of primary and secondary sources, we will examine how scientific ideas about race developed in concert with European imperial expansion and slavery; how these ideas were employed in legal cases, medical practice, and eugenics policies; and how activists and scholars have challenged racist practices and ideas. Finally, we will turn to the recent resurgence of racial thinking in biology and medicine in the light of the history of race and science. Not offered 2025-26.

Hum/H/HPS 15. Waste in the World. *9 units (3-0-6); second, third terms.* The things that human beings make and throw away rarely stay where we put them. Just as humans have shaped the biological and physical world, the biological and physical world shapes human actions. In this course, we will examine how these interacting forces propel environmental and cultural change. We will explore these concepts through the lens of waste - how different groups at different points in history define waste, where discarded things go and what they become as they move through space and time. We will consider how conflicting perceptions of utility and waste in different cultural and historical contexts have factored into shifting ideas about race, class, gender, wilderness, technology, consumption, and sovereignty. In rethinking waste, we will explore the multiple meanings of "nature," assess the roots of sustainability, and evaluate past events in light of current ideas about environmental justice. While this course prioritizes reading and discussion, we will also engage with the world around us through visual analysis. Pasadena and Los Angeles will be among our most important resources, allowing us to ground global ideas in a local context. Not offered 2025-26.

Hum/H 16. Environment and Environmental Expertise in Premodern World. *9 units (3-0-6); third term.* This course offers an introduction to environmental history with a particular focus on the field's intersection with the histories of science and knowledge. We will discuss how historians write about the environment in the past, how they approach

the interactions of states and societies with the environment, as well as examining what and how people in the past knew about their environments. The course will stretch chronologically and geographically and cover a broad range of topics from Graeco-Roman Antiquity in the Mediterranean, through the early modern Atlantic world, to the early nineteenth-century United States. We will examine people's interactions with climate, forests, waterways, wildlife, and natural disasters, to name just a few themes, and learn how societies understood, described, and managed the natural world in premodern times. Instructor: Falkowski.

Hum/H 17. Vast Early America. *9 units (3-0-6); first, second term.* Traditional histories of the United States usually begin with the so-called original Thirteen Colonies-the British territories that eventually banded together and formed the early United States. But these colonies comprised only a small sliver of North America, which was (and is) an expansive, dynamic, and diverse place. This course focuses on that larger history and on the complex and sometimes violent meetings of a variety of different cultures, peoples, and environments that happened in North America between 1450 and 1850. Topics will include the histories of Indigenous peoples, enslaved Africans, and women; the meeting of different European empires; the movement of plants, animals, and microbes between continents; the relationship between different North American regions like the Caribbean, Southwest, and Northeast. This course will also explore the relationship between historic events and the national mythology of United States and ask students to reflect on why early American history matters in the present day. Instructor: Jones.

Hum/H/HPS 18. Introduction to the History of Science. *9 units (3-0-6); second, third terms.* Major topics include the following: What are the origins of modern Western science, when did it emerge as distinct from philosophy and other cultural and intellectual productions, and what are its distinguishing features? When and how did observation, experiment, quantification, and precision enter the practice of science? What were some of the major turning points in the history of science? What is the changing role of science and technology? Using primary and secondary sources, students will take up significant topics in the history of science, from ancient Greek science to the 20th-century revolution in physics, biology, and technology. Hum/H/HPS 10 may be taken for credit toward the additional 36-unit HSS requirement by HPS majors and minors who have already fulfilled their first-year humanities requirement and counts as a history course in satisfying the first-year humanities breadth requirement. Instructor: Feingold.

Hum/H 19. Righting the Wrongs of History. *9 units (3-0-6); third term.* In recent years, growing numbers of people committed to equity and social justice have discussed various ways of addressing historical injustices whose harms are still experienced in the present. Some have proposed monetary restitution and other restorative strategies that account for resources, opportunities, and lives lost. Others have advocated more symbolic reparative approaches that seek to heal the psychic wounds of injustice. This course will examine efforts to right the wrongs of history,

with particular attention given to the decades-long movement for reparations for African Americans and recent efforts to address difficult histories at Caltech. Investigating initiatives that have been realized and others that have been only imagined, in this course we will seek to understand both the possibilities and impossibilities of repairing historical harms. Not offered 2025-26.

Hum/H/HPS 20. COVID-19 and Other Pandemics: Science, Medicine, and Public Controversies. *9 units (3-0-6); first term.* This course will analyze the COVID-19 pandemic in the context of other similar events in the history of public health and medicine. How do we understand the COVID pandemic and the differential responses to it around the globe? What is the best framework for proper understanding? Science, history, politics, culture? Special attention will be given to the state of medical science today and in the past, the understanding of ethology, transmission, and symptoms; the role of scientists, physicians, and "quacks"; the persistence and change in the forms of fear, superstition, and misinformation across time. Instructor: Kormos-Buchwald.

Hum/H 38. Leonardo da Vinci & Co.: How to Understand Technological Invention in the Long Renaissance. *9 units (3-0-6); second term.* How do we understand technology? How do we define technological invention? How does technological innovation circulate? This course explores major technological achievements across different historical contexts, with a particular focus on the Mediterranean world between the 14th and 17th centuries. It also examines processes of technological transfer among Asia, Europe, Africa, and the Americas. We will investigate how technological innovations emerged, circulated, interacted, and shaped societies-as well as new ideas in science. Analyzing the concept of invention will be especially useful in critically assessing traditional narratives of rupture-such as the Renaissance and the Scientific Revolution-as well as narratives of continuity in the development of scientific knowledge and technology. Students will take part in collaborative projects, including 3D-printing historical tools and machines. They will also work with sources from special collections in libraries, museums, and archives. Instructor: Zanetti.

Hum/H 47. Religion in America, from the Reformation to the Rapture. *9 units (3-0-6); first term.* This course is an introduction to the study of American religion, with a focus on how different groups and communities have practiced their faith in different eras. Starting with an overview of Reformation-era battles over doctrine and ritual, the course then considers Native, African, and European roots of colonial American religious culture; the legal and political history of church and state after the Revolution; the place of women in major religious traditions; the emergence in the U.S. of immigrant communities of believers representing the world's major religions in the 19th and 20th centuries; and contemporary battles over religion in public. Instructor: Juster.

Hum/H 53. The Early Islamic World (c. 600-1453). *9 units (3-0-6); third term.* In the middle of the seventh century, the tribal followers of a new

religion called Islam burst out of the deserts of the Arabian Peninsula and rapidly overwhelmed the armies of the ancient Byzantine and Sassanid Empires. By the middle of the next century, they had conquered much of the western Eurasian world, from the Central Asian steppe to the Straits of Gibraltar. The Muslims' extraordinary achievement bound together lands formerly ruled by two ancient empires-the Roman and Persian-and transformed the cultures, societies, economies, and laws of the diverse peoples now subject to their rule. This course explores the political, social, and institutional history of the Islamicate world from its origins in seventh-century Arabia to the Ottoman conquest of Constantinople in 1453. It will pay particular attention to relations between Islam and the other cultures of the Mediterranean as they are revealed in episodes such as the conquest of Spain, the Crusades, and repeated conflicts with the Byzantine Empire. It will also explore internal political, cultural, and religious conflict among the followers of Islam themselves. Instructor: Morgan.

Hum/H 57. Special Topics in Humanities/History. *Units are by arrangement; Offered by announcement.* This course will count as a first-year humanities course in history. It is usually taught by new or visiting faculty. This course is not repeatable. Limited to 15 students. See registrar's announcement for details. Instructor: Staff.

H 60. Reading in History. *Units to be determined for the individual by the division; any term.* Reading in history and related subjects, done either in connection with the regular courses or independently, but under the direction of members of the department. A brief written report will usually be required. Graded pass/fail. Not available for credit toward humanities-social science requirement.

E/H/VC 89. New Media Arts in the 20th and 21st Centuries. *9 units (3-0-6);* For course description, see Engineering

H 98. Reading in History. *9 units (1-0-8); Prerequisites: instructor's permission.* An individual program of directed reading in history, in areas not covered by regular courses. Instructor: Staff.

H 99 abc. Research Tutorial. *9 units (1-0-8); Prerequisites: instructor's permission.* Students will work with the instructor in the preparation of a research paper, which will form the basis of an oral examination. Instructor: Staff.

VC/H 102. Looking East/Looking West. *9 units (3-0-6);* For course description, see Visual Culture

H 107. The Early Middle Ages. *9 units (3-0-6); second term.* This course is designed to introduce students to the formative period of Western medieval history, from roughly 300 to 1000 CE. It will emphasize the development of a new civilization from the fusion of Roman, Germanic, and Christian traditions, with a focus on the Frankish world. The course focuses on the reading, analysis, and discussion of primary sources.

Instructor: Brown.

H 108. The High Middle Ages. *9 units (3-0-6); third term.* This course is designed to introduce students to European history between 1000 and 1400. It will provide a topical as well as chronological examination of the economic, social, political, and religious evolution of western Europe during this period, with a focus on France, Italy, England, and Germany. The course emphasizes the reading, analysis, and discussion of primary sources. Instructor: Brown.

H 109. Medieval Knighthood. *9 units (3-0-6); third term.* This course tells the story of the knight from his beginnings in the early Middle Ages, through his zenith in the 11th, 12th, and 13th centuries, to his decline and transformation in the late medieval and early modern periods. The course treats the knight not simply as a military phenomenon but also as a social, political, religious, and cultural figure who personified many of the elements that set the Middle Ages apart. Not offered 2025-26.

H 110. Environment and Empire in the Early Modern Atlantic World. *9 units (3-0-6); first.* According to earth scientists, European colonization of the Americas constituted an ecological disaster of global proportions. The environmental impact of colonization, however, was experienced at every scale as new people, animals, plants, and microbes collided in unprecedented and unanticipated ways. This course will explore all of these scales and introduce students to both the field of environmental history and to the Atlantic World, a term used by scholars to describe interactions between Europeans, Africans, and Americans from the fifteenth to the nineteenth century. The major themes of this course will be the exploration and exploitation of the natural world by Europeans, the creation of knowledge about the natural world, the use of environment as a tool of resistance by enslaved Africans and Indigenous peoples and changing views of the natural world throughout the early modern period. Not offered 2025-26. .

H 111. The Medieval Church. *9 units (3-0-6); second term.* This course takes students through the history of the medieval Christian Church in Europe, from its roots in Roman Palestine, through the zenith of its power in the high Middle Ages, to its decline on the eve of the Reformation. The course focuses on the church less as a religion (although it will by necessity deal with some basic theology) than as an institution that came to have an enormous political, social, cultural, and economic impact on medieval life, and for a brief time made Rome once more the mistress of Europe. Not offered 2025-26.

H 112. The Vikings. *9 units (3-0-6); second term.* This course will take on the Scandinavian seafaring warriors of the 8th-11th centuries as a historical problem. What were the Vikings, where did they come from, and how they did they differ from the Scandinavian and north German pirates and raiders who preceded them? Were they really the horned-helmeted, bloodthirsty barbarians depicted by modern popular media and by many medieval chronicles? What effect did they have in

their roughly two centuries of raiding and colonization on the civilizations of medieval and ultimately modern Europe? Not offered 2025-26.

H 113. Books, Readers, and Science in Early Modern Europe. *9 units (3-0-6); first term.* This course introduces topics and methods in the history of the book and reading. It focuses on the representation of knowledge in early modern printed materials across contemporary disciplines, which include natural history, technical arts, geography, music, and philology. We will examine in detail how scholars, editors, and printers translated new discoveries in sciences and humanities to text and images, thus learning about the communication and reception of knowledge in early modern Europe. We will study books, maps, and broadsheets, asking questions about the advantages and limits of print as a method of knowledge dissemination as well as the objectivity of the representation of research findings. The course focuses on the period between 1500-1800, with a final foray into the nineteenth and twentieth century to investigate the development and characteristics of scientific photography. Instructor: Falkowski.

H 114. Native North America. *9 units (3-0-6); first, second terms.* North America is populated by a multitude of Indigenous peoples who have shaped the cultures, politics, and environments here since time immemorial. Indigenous nations moreover controlled the vast majority of North America until at least the middle of the nineteenth century. Today, there are 574 federally recognized Native American tribes, each with a unique culture and history, making it impossible to fit all of Native American history into a single narrative. As a result, this course explores different episodes within a larger period of rapid change in Native American history: the period between the fifteenth and nineteenth centuries. This course will explore both how selected nations responded and adapted to larger changes happening across North America and critical themes and concepts within Native and Indigenous Studies. Students will also be asked to connect what they are learning to current events involving Indigenous people. Instructor: Jones.

H 115. Instruments of Knowledge from Antiquity to the Early Modern World. *9 units (3-0-6); third term.* This course examines the development of scientific instruments from Antiquity to the Early Modern period, with a particular focus on the Euro-Mediterranean region. Students will explore questions such as: What defines a scientific instrument? How did science shape scientific instruments, and how did scientific instruments, in turn, shape science? The course will investigate how instruments emerged, interacted, and contributed to evolving scientific paradigms. Special attention will be given to the unexpected role played by now-obsolete scientific traditions-ranging from alchemy and astrology to Aristotelian meteorology-in influencing the design and function of some of the most revolutionary scientific instruments in history. A key component of the course will be hands-on learning: students will analyze and reconstruct historical instruments using replicas and digital tools, including 3D-printed models, and visit museum, library, and archive collections. Instructor: Zanetti.

H 116. Tying the Knot: Marriage in the Medieval Christian and Islamic Worlds. *9 units (3-0-6); first term.* This course examines the meaning, practice, and religious significance of marriage in both the Christian and Islamic worlds during the Middle Ages. It focuses on the diverse religious, cultural, and social meanings of marriage as expressed in literary texts like hagiographies and histories, as well as the contested legal and doctrinal aspects of matrimony argued over by lawyers, jurists, and theologians. Particular attention will be paid to analysis of archival legal sources like marriage contracts and disputes which shed light on marriage practices, gender dynamics, and family relationships in the medieval world. Instructor: Morgan.

H 117. Laying Down the Law: Legal Culture in the Medieval Mediterranean, c. 530-1230. *9 units (3-0-6); second term.* Medieval law can seem strange from a modern perspective. Why was trial by battle acceptable? Why were forgery and murder both crimes punishable by death? How did religion impact law? The strangeness of medieval law reminds us that our ways of thinking about the law-our assumptions about why it exists and how it should work-are conditioned by our contemporary cultural and social values. In this course we will examine the diverse legal traditions of the medieval Mediterranean-European, Byzantine, and Islamicate law-to better understand law as a dynamic aspect of medieval societies and cultures. The course will introduce students to the methodology and theory of legal history and encourage them to consider from this perspective the political, social, and cultural factors which influence our modern attitudes towards law. Instructor: Morgan.

H 123. Ordinary People: Uncovering Everyday Life in the European Past. *9 units (3-0-6); second term.* In the historical record, much attention is given to wealthy elites (rulers and lawmakers, aristocrats, wealthy merchants), since they were the ones who left written records of their political and economic activities and their personal affairs. But what about the vast majority of people who lived in the past, most of whom were barely literate and had little opportunity to 'make history'? What can we know about them? This class focuses on the lives of ordinary people, and the sources historians use to learn about them. Special attention will be given to women, the poor, and other marginalized groups in societies ranging from England in the west to Russia in the east. Not offered 2025-26.

H 124. Russia. *9 units (3-0-6); first term.* Current events have us looking to the past for explanations. How does Russian history help us to understand what is happening in Russia today? Contemporary political commentary emphasizes the recent past: the history of the Soviet Union and its collapse in 1991. This course takes a longer look at Russian political, economic, social, and cultural history - from imperial Russia to the present day. The emphasis is on longer continuities over eras: tsarist, Soviet, post-Soviet. Topics covered include the nature and role of the state, internal politics, rule of law and property rights, serfdom,

inequality, art and social commentary, popular resistance, censorship, and the effects of all of these on the lives of ordinary Russians. Not offered 2025-26.

H 125. Soviet Russia. *9 units (3-0-6); first term.* Why was the Russian Revolution of 1917 successful? And how did the Soviet system survive nearly 75 years? These questions will be addressed in the wider context of Russian history, with a focus on political, economic, and social institutions in the pre- and post-revolutionary period. Subjects covered include the ideological underpinnings of Bolshevism, Lenin and the Bolshevik coup, the rise of Stalin, collectivization, socialist realism, the command economy, World War II, the Krushchev 'thaw', dissident culture and the arts, popular culture, and Gorbachev's perestroika. A variety of sources will be used, including secondary historical literature, fiction, film, and art. Not offered 2025-26.

H/HPS 129. History of Satellites: From Sputnik to Starlink. *9 units (3-0-6); third term.* The artificial satellites encircling the planet make up a global information infrastructure. Most of us living in industrialized regions use satellites daily without even realizing it. How did satellites become so integral to terrestrial technological systems? How did Earth orbit transform from a wilderness into a landscape during the second half of the 20th century, and how is that landscape changing in the 21st? We will trace the history of satellites beginning with the first artificial "moons" and moving into the current moment of private industry ascendance, taking into account the development, use, and decay of these technologies. We will consider how designers and users shape satellites, and map out the ways that objects in orbit reflect and reinforce power and geopolitics on the ground below. Not offered 2025-26.

H/HPS 130. Critical Infrastructures. *9 units (3-0-6); third term.* In much of mainstream American culture an enthusiasm for innovation can overshadow the older, established technologies that (often invisibly) sustain society. In this course, we will examine the interplay of environment, technology, and labor that shapes infrastructures and the acts of maintenance that sustain these naturalized systems. We will explore the history and politics of local and regional networks including but not limited to energy, transportation, and information. This course includes site visits and presentations by campus infrastructure experts that help guide our critical encounters with the naturalized technological systems that support daily life and work at Caltech, and which both connect us to and separate us from the surrounding region. Not offered 2025-26. .

H/HPS 131. History of Extinction. *9 units (3-0-6); first and third terms.* Humans are in the midst of the sixth mass extinction-the first to be caused by human activity. Extinction has been viewed in changing ways over the past 200 years, and this course takes an interdisciplinary approach to learning about the extinction process from a historical as well as a modern perspective. Our focus will be on the extinction of biological entities, but we will also touch on other systems that have

disappeared: languages, technologies, habitats, and ways of living. Central to our endeavors will be asking what it means to live in this time of loss: Should we mourn? And if so, how do we mourn for what many or most of us do not see, but only read about? Finally, we will scrutinize what the practical effects of extinction have been, are, and will be. We will also make at least one visit to a natural history museum to view some extinct species behind the scenes. Instructor: Lewis.

H/HPS 132. Humanistic Ecology. *9 units (3-0-6); third term.* Humans' conceptions of nature have changed dramatically over time. Ecological systems influence human culture, politics, law, and many other spheres, and in turn, humans influence those systems. This class introduces students to the field of humanistic ecology-a discipline that looks to a number of cultural, political, historical and economic elements to better understand the role of ecology in a larger sphere outside of its scientific structure and uses. Humanistic ecology is designed to provide context for the study of ecology, and in a fundamental way, focuses on the appropriate role of humanity in its relationship to nature: what is ethical, or not, what is useful, or not, and a variety of other matters that should be considered when taking a fully three-dimensional view of ecological science. Not offered 2025-26.

H/HPS 133. Forests and Humans. *9 units (3-0-6); first term.* Forests - which cover 31 percent of the world's land surface - have played essential roles in enhancing the planet's biodiversity. Forests have also served humans in numerous and often controversial ways, and have also been subjected to dramatic change through human activity. How well have we served forests, as well as being served by them? The class will cover the growth and use of forests from a humanistic and historic perspective, as well as discussions about the role of fire in forests, with a particular emphasis on the unprecedented forest fires in California in the past several years and the global ecological implications. Not offered 2025-26.

H/HPS 134. Birds, Evolution, Speciation and Society. *9 units (3-0-6); second term.* The cultural, scientific, social and political roles of birds make them an excellent lens through which to view humans' interactions with the natural world. This course will cover our changing understandings of birds, starting with hawking and falconry in earlier centuries, through the discovery of new species, up through Darwinian understandings of speciation and evolution, and continuing up to present scientific understandings of birds' capabilities and their ties to humankind, as well as to other anchors in the natural world. We will take a strong biographical as well as avian approach to understanding key personalities who furthered our understandings of avian science. Not offered 2025-26.

H 136. Caltech in the Archives. *9 units (3-0-6); first term.* This class will introduce students to the methods of archival work in the humanities and social sciences. Over the course of the quarter students will receive an introduction to factors surrounding the collection, organization, and use

of various types of archives as a background to several small-scale projects working in an archival collection of their own choosing. The seminar will center around weekly projects and synthetic analytical essays about the archival process and archival discoveries. Students hoping to combine their course work with an archive-based research paper may sign up for a separate independent study and conduct research concurrently, with instructor approval. Not offered 2025-26.

H 137. Criminals, Outlaws, and Justice in a Thousand Years of Chinese History. *9 units (3-0-6); first term.* This course explores the shifting boundary between discourses of crime and disobedience over the last millennium or so of Chinese history. It offers fictional, philosophical, political, propagandistic, official, and personal writings on crime and those who commit it as a basis for a wide-ranging series of discussions about when breaking the law is good, when breaking the law is bad, and who gets to decide where the line between a criminal and an outlaw should be drawn. Not offered 2025-26.

H 138. The Way. *9 units (3-0-6); first term.* This course introduces students to some of the seminal writings on the meaning of life, the essentials of rulership, and the place of the individual in the universe from the history of Chinese thought and philosophy. Students are given selected readings from several schools of thought in Chinese history, with an emphasis on the formative Warring States era (the period of the Hundred Schools of classical Chinese philosophy). Instead of being asked to write expository or argumentative essays, participants in this seminar will be introduced to analyzing and presenting texts using the method of annotation. Exposure to the principles of annotation will provide students with a new approach to analyzing and talking about texts both within a humanistic context and beyond. Not offered 2025-26.

H 139. Translation Theory and Practice (Chinese Historical Sources Seminar). *9 units (3-0-6); first term.* This seminar will introduce students to the problems and practices of historical translation for academic purposes, with a focus on primary materials from Chinese history. Students will take responsibility for an individual translation project, participate in seminar discussions and collaborative projects to improve the translations being made, and discuss the philosophical and methodological questions at the heart of the practice of translation. Advanced proficiency in written Chinese is required. Students who write analyses (4,000 words) of the sources being translated may enroll in this class as H 139, which satisfies the advanced humanities credit. Not offered 2025-26.

H/L 142. Perspectives on History through Russian Literature. *9 units (3-0-6); first term.* The Russian intelligentsia registered the arrival of modern urban society with a highly articulate sensitivity, perhaps because these changes-industrialization, the breakdown of traditional hierarchies and social bonds, the questioning of traditional beliefs-came to Russia so suddenly. This gives their writings a paradigmatic quality; the modern dilemmas that still haunt us are made so eloquently explicit

in them that they have served as models for succeeding generations of writers and social critics. This course explores these writings (in English translation) against the background of Russian society, focusing especially on particular works of Chekhov, Dostoevsky, Goncharov, Tolstoy, and Turgenev. Not offered 2025-26.

H 149. Age of Fracture: America Since 1974. *9 units (3-0-6); third term.* In this course, we will examine America after Richard Nixon's resignation in 1974, a period that historians have referred to as an age of fracture and social disaggregation. Using fracture as a conceptual framework to investigate American politics and culture in the last quarter of the twentieth century, we'll consider how the recent past has informed present-day American society. Themes of study will include the culture wars, political polarization, globalization, and the growing wealth gap. In addition, we'll investigate the theoretical and methodological challenges of doing recent history. Not offered 2025-26.

H 152. Where Do We Go from Here? Black America in the Post-Civil Rights Era. *9 units (3-0-6); first term.* This course will examine African American politics, culture, and society in the decades following the passage of landmark civil rights legislation in the 1960s. Topics of discussion will include deindustrialization and the rise of hip hop culture, black feminist and queer thought, debates over welfare and affirmative action, and mass incarceration. Analyzing a variety of political and cultural artifacts as well as cutting-edge secondary literature, we will investigate various moments in recent African American history to gain insight into changing notions of rights, citizenship, equality, and freedom in American society. Not offered 2025-26.

H/HPS 153. Inequality and Environment. *9 units (3-0-6); first term.* This seminar introduces students to the history of environmental inequality, environmental racism, and environmental justice. Human bodies are inescapably enmeshed in our environments: human health and environmental health are inseparable. But environmental burdens and benefits are distributed unevenly along lines of race, gender, class, and nationality. We will examine local, national, and transnational case studies to understand the historical development of environmental inequalities and movements for environmental justice. We will consider different methods for studying environmental injustice and the politics of environmental knowledge. Not offered 2025-26.

H/HPS 154. Feminist Science Studies. *9 units (3-0-6); second term.* This seminar offers an introduction to scholarship on gender and science. Feminist science studies can seem oxymoronic: the objectivity on which science depends appears opposed to the political commitments feminism implies. Scholars in feminist science studies, however, argue that feminist theory and methods can in fact improve scientific practice. This course will introduce students to the historical development of feminist Science & Technology Studies and what this field tells us about the history of women in science, the history of scientific theories of sex/gender, and the future of feminist research. This

reading-heavy class will also include discussions of feminist epistemology, feminist research methods, and new directions in feminist STS. Not offered 2025-26.

H/HPS 155. Mortality Crises and Social Change: Epidemic Disease from 1300 to the Present. *9 units (3-0-6); third term.* What do we know about epidemics in the past? What did contemporaries understand about these events? How did societies respond to periodic bouts of epidemic disease? This course examines mortality crises and epidemics from the Black Death in the 14th century to the current coronavirus pandemic, with attention given to the impact of epidemics on societies, the ways in which such outbreaks have been understood over time and the kinds of responses they have elicited. We will draw on studies for a range of societies in order to identify patterns across space and time, and to highlight both continuity and change in the ways societies have dealt with contagious diseases. Not offered 2025-26.

HPS/H 160. Einstein on the Run: European Scientists Fleeing Fascism, War, and the Holocaust. *9 units (3-0-6); first term.* Structured around the life and work of Albert Einstein (1879-1955), the course will focus on the 1930s and 1940s, including the discovery of nuclear fission and the making of the atom bomb. Colleagues of Einstein, such as Max Born, Hans Bethe, Enrico Fermi, Lise Meitner, Erwin Schrodinger, and untold numbers of students, scientists, and engineers were forced out of their universities and laboratories by the rise of Fascism in Europe and sought shelter in the United States and elsewhere. Many contributed to the Allied World War II effort. Einstein himself became a facilitator for immigrant scientists, intellectuals, and artists seeking refuge. We shall use historical documents from the Einstein Archives to understand the complex collective and individual experiences and their impact on developments in science and technology during this turbulent historical period. Instructor: Kormos-Buchwald.

H 161. Selected Topics in History. *9 units (3-0-6); offered by announcement.* This is an advanced humanities course on a specialized topic in History. It is usually taught by new or visiting faculty. The course may be re-taken for credit except as noted in the course announcement. Limited to 15 students. See registrar's announcement for details. Instructors: Staff, visitors.

HPS/H 162. Social Studies of Science. *9 units (3-0-6); third term.* A comparative, multidisciplinary course that examines the practice of science in a variety of locales, using methods from the history, sociology, and anthropology of scientific knowledge. Topics covered include the high-energy particle laboratory as compared with a biological one; Western as compared to non-Western scientific reasoning; the use of visualization techniques in science from their inception to virtual reality; gender in science; and other topics. Instructor: Feingold.

HPS/H 166. Historical Perspectives on the Relations between Science and Religion. *9 units (3-0-6); second term.* The course develops

a framework for understanding the changing relations between science and religion in Western culture since antiquity. Focus will be on the ways in which the conceptual, personal, and social boundaries between the two domains have been reshaped over the centuries. Questions to be addressed include the extent to which a particular religious doctrine was more or less amenable to scientific work in a given period, how scientific activity carved an autonomous domain, and the roles played by scientific activity in the overall process of secularization. Instructor: Feingold.

HPS/H 167. Experimenting with History/Historic Experiment. *9 units (3-0-6); third term. Prerequisites: Ph 1 abc, and Ph 2 abc (may be taken concurrently).* This course uses a combination of lectures with hands-on laboratory work to bring out the methods, techniques, and knowledge that were involved in building and conducting historical experiments. We will connect our laboratory work with the debates and claims made by the original discoverers, asking such questions as how experimental facts have been connected to theories, how anomalies arise and are handled, and what sorts of conditions make historically for good data. Typical experiments might include investigations of refraction, laws of electric force, interference of polarized light, electromagnetic induction, or resonating circuits and electric waves. We will reconstruct instrumentation and experimental apparatus based on a close reading of original sources. Not offered 2025-26.

HPS/H 168. History of Electromagnetism and Heat Science. *9 units (3-0-6); second term. Prerequisites: Ph 1 abc, and Ph 2 abc (may be taken concurrently).* This course covers the development of electromagnetism and thermal science from its beginnings in the early 18th century through the early 20th century. Topics covered include electrostatics, magnetostatics, electrodynamics, Maxwell's field theory, the first and second laws of thermodynamics, and statistical mechanics as well as related experimental discoveries. Not offered 2025-26.

HPS/H 169. Selected Topics in the History of Science and Technology. *9 units (3-0-6);* This is an advanced humanities course on a specialized topic in HPS and History. It is usually taught by new or visiting faculty. The course may be re-taken for credit except as noted in the course announcement. Limited to 15 students. See registrar's announcement for details. Instructors: Staff, visiting lecturers.

HPS/H 170. History of Light from Antiquity to the 20th Century. *9 units (3-0-6); first term. Prerequisites: Ph 1 abc, and Ph 2 abc (may be taken concurrently).* A study of the experimental, mathematical, and theoretical developments concerning light, from the time of Ptolemy in the 2nd century A.D. to the production of electromagnetic optics in the 20th century. Instructor: Buchwald.

HPS/H 171. History of Mechanics from Galileo through Euler. *9 units (3-0-6); Prerequisites: Ph 1 abc, and Ph 2 abc (may be taken concurrently).* This course covers developments in mechanics, as well as related aspects of mathematics and models of nature, from just before

the time of Galileo through the middle of the 18th century, which saw the creation of fluid and rotational dynamics in the hands of Euler and others. Not offered 2025-26.

HPS/H 172. History of Mathematics: A Global View with Close-ups. *9 units (3-0-6); offered by announcement.* The course will provide students with a brief yet adequate survey of the history of mathematics, characterizing the main developments and placing these in their chronological, cultural, and scientific contexts. A more detailed study of a few themes, such as Archimedes' approach to infinite processes, the changing meanings of "analysis" in mathematics, Descartes' analytic geometry, and the axiomatization of geometry c. 1900; students' input in the choice of these themes will be welcomed. Not offered 2025-26.

HPS/H 175. Matter, Motion, and Force: Physical Astronomy from Ptolemy to Newton. *9 units (3-0-6); second term.* The course will examine how elements of knowledge that evolved against significantly different cultural and religious backgrounds motivated the great scientific revolution of the 17th century. Not offered 2025-26.

HPS/H 180. Forbidden Knowledge. *9 units (3-0-6); first term.* Why does the notion of freedom of knowledge and teaching in science and engineering matter? What kinds of restrictions have been placed on scientists and engineers, their publications and institutions? Who restrained scientific and engineering knowledge of what sorts; for what reasons; and how successfully? These questions will be addressed by exploring the strategies developed by the U.S. research community to protect the international circulation of knowledge after World War II, when scientific freedom and the export of technical data had to be balanced with the needs of national security. Case studies will include the atomic bomb, the semiconductor industry in the 1970s and space technologies, notably rockets/missiles, in the 1990s. The threat to U.S. economics and military security posed by the Soviet Union in the Cold War, and by China today, has transformed the practice of research in university and in industry alike building new walls around the production and circulation of knowledge to affirm national sovereignty that is, all the while, being undermined by the global circulation of trained scientists and engineers. Not offered 2025-26.

H/HPS/VC 185. Angels and Monsters: Cosmology, Anthropology, and the Ends of the World. *9 units (3-0-6); second term.* This course explores late medieval European understandings of the origins, structure, and workings of the cosmos in the realms of theology, physics, astronomy, astrology, magic, and medicine. Attention is given to the position of humans as cultural creatures at the intersection of nature and spirit; as well as to the place of Christian Europeans in relation to non-Christians and other categories of outsiders within and beyond Europe. We will examine the knowledge system that anticipated racializing theories in the West. Instructor: Wey-Gomez.

H/HPS/VC 186. From Plato to Pluto: Maps, Exploration and Culture from Antiquity to the Present. *9 units (3-0-6); second term.* This course covers a broad range of topics in the history of maps and exploration from Antiquity to the present. These topics range from the earliest visualizations of earth and space in the Classical world to contemporary techniques in interplanetary navigation. By way of maps, students will explore various ways in which different cultures have conceptualized and navigated earth and space. While maps emulate the world as perceived by the human eye, they, in fact, comprise a set of observations and perceptions of the relationship between bodies in space and time. Thus, students will study maps, and the exploration they enable, as windows to the cultures that have produced them, not only as scientific and technical artifacts to measure and navigate our world. Not offered 2025-26.

H/L 191. Perspectives on History through German Literature. *9 units (3-0-6); third term.* Industrialization, economic growth, and democracy came to Germany much later than to England and France, and the forms they took in Germany were filtered through the specific institutional character of Central Europe. German-speaking writers and intellectuals saw these trends from the perspective of indigenous intellectual traditions, and the resulting collisions of values and priorities largely shaped European and American social, political, and literary debates for much of the nineteenth and twentieth centuries. This course explores these writings (in English translation) against the historical background of Central European society, focusing on particular works of Goethe, Hoffmann, Heine, Nietzsche, Kafka, Rilke, and Mann. Not offered 2025-26.

H 192. The Crusades. *9 units (3-0-6); third term.* This course will introduce students to the series of religiously motivated European invasions of the Middle and Near East that began at the end of the eleventh century and that led to the creation of Latin Christian principalities in Palestine. Though the crusading movement came to embroil much of Europe itself, the course will focus strictly on the military expeditions to what the Crusaders called the Holy Land, and the history of the Crusader states up to the point of their destruction at the end of the thirteenth century. The course will be guided by the following questions: how did medieval Christianity justify wars of aggression against foreign peoples and religions? What motivated western Europeans to leave their homes and march into a hostile environment, where they often faced impoverishment if not death and where maintaining a Christian presence was a constant struggle? How did they manage to erect stable political entities in alien territory that lasted as long as they did, and how did they have to adapt their own culture to do so? Finally, how did the native peoples of the regions the Crusaders invaded and conquered-Muslim but also Christian and Jewish - perceive the Crusaders? How did the Crusaders' presence affect life in a region whose populations had their own ancient histories and patterns of life? Not offered 2025-26.

En/H 193. Cervantes, Truth or Dare: Don Quixote in an Age of Empire. *9 units (3-0-6);* For course description, see English

H 201. Reading and Research for Graduate Students. *Units to be determined for the individual by the division;*

HISTORY AND PHILOSOPHY OF SCIENCE

Hum/H/HPS 14. Race, Science, and Medicine in U.S. History. *9 units (3-0-6);* For course description, see Humanities

Hum/H/HPS 15. Waste in the World. *9 units (3-0-6);* For course description, see Humanities

Hum/H/HPS 18. Introduction to the History of Science. *9 units (3-0-6);* For course description, see Humanities

Hum/H/HPS 20. COVID-19 and Other Pandemics: Science, Medicine, and Public Controversies. *9 units (3-0-6);* For course description, see Humanities

HPS 90. Public Lecture Series. *1 unit; first, second, third terms.* Students attend four lectures, featuring speakers from outside Caltech, on topics in the history and philosophy of science. Students may choose from a variety of regularly scheduled HPS lectures, including HPS seminars, Harris lectures, and History seminars (history or philosophy of science only). Graded on attendance. Not available for credit toward the humanities-social science requirement. Graded pass/fail. Instructor: Visiting lecturers.

HPS 98. Reading in History and Philosophy of Science. *9 units (1-0-8); Prerequisites: instructor's permission.* An individual program of directed reading in history and philosophy of science, in areas not covered by regular courses. Instructor: Staff.

HPS 102 ab. Senior Research Seminar. *12 units (2-0-10);* Offered in any two consecutive terms, by arrangement with HPS faculty. Under the guidance of an HPS faculty member, students will research and write a focused research paper of 15,000 words (approximately 50 pages). Work in the first term will comprise intensive reading in the relevant literature and/or archival or other primary source research. In the second term, students will draft and revise their paper. Open to seniors in the HPS option and to others by special permission of an HPS faculty member. Not offered 2025-26.

HPS/PI/CS 110. Causation and Explanation. *9 units (3-0-6); third term.* An examination of theories of causation and explanation in philosophy and neighboring disciplines. Topics discussed may include probabilistic and counterfactual treatments of causation, the role of statistical

evidence and experimentation in causal inference, and the deductive-nomological model of explanation. The treatment of these topics by important figures from the history of philosophy such as Aristotle, Descartes, and Hume may also be considered. Instructor: Eberhardt.

HPS/Pl 120. Introduction to Philosophy of Science. *9 units (3-0-6); second term.* An introduction to fundamental philosophical problems concerning the nature of science. Topics may include the character of scientific explanation, criteria for the conformation and falsification of scientific theories, the relationship between theory and observation, philosophical accounts of the concept of "law of nature," causation, chance, realism about unobservable entities, the objectivity of science, and issues having to do with the ways in which scientific knowledge changes over time. Instructor: Hitchcock.

HPS/Pl 122. Probability, Evidence, and Belief. *9 units (3-0-6); second term.* Philosophical and conceptual issues arising from the study of probability theory and how it relates to rationality and belief. Topics discussed may include the foundations and interpretations of probability, arguments for and against the view that we ought to have personal degrees of belief, rational change in beliefs over time, and the relationship between probability and traditional epistemological topics like evidence, justification, and knowledge. Not offered 2025-26.

HPS/Pl 123. Introduction to the Philosophy of Physics. *9 units (3-0-6); third term. Prerequisites: Ph 1 abc or instructor's permission.* This course will examine the philosophical foundations of the physical theories covered in the first-year physics sequence: classical mechanics, electromagnetism, and special relativity. Topics may include: the goals of physics; what laws of nature are; the unification of physical theories; symmetries; determinism; locality; the reality of fields; the arrow of time. Instructor: Sebens.

HPS/Pl 124. Philosophy of Space and Time. *9 units (3-0-6); third term.* This course will focus on questions about the nature of space and time, particularly as they arise in connection with physical theory. Topics may include the nature and existence of space, time, and motion; the relationship between geometry and physical space (or space-time); entropy and the direction of time; the nature of simultaneity; and the possibility of time travel. Not offered 2025-26.

HPS/Pl 125. Philosophical Issues in Quantum Physics. *9 units (3-0-6); third term. Prerequisites: Ph 2 b, Ph 12 b, or Ch 21 a.* This course will focus on philosophical and foundational questions raised by quantum physics. Questions may include: Is quantum mechanics a local theory? Is the theory deterministic or indeterministic? What is the role of measurement and observation? Does the wave function always obey the Schrödinger equation? Does the wave function give a complete description of the state of a system? Are there parallel universes? How are we to understand quantum probabilities?. Instructor: Sebens.

HPS/PI 128. Philosophy of Mathematics. *9 units (3-0-6); second term.* An examination of conceptual issues that arise in mathematics. The sorts of issues addressed may include the following: Are mathematical objects such as numbers in some sense real? How do we obtain knowledge of the mathematical world? Are proofs the only legitimate source of mathematical knowledge? What is the relationship between mathematics and the world? How is it possible to apply abstract theory to the world? Views of major historical figures such as Plato, Hume, Kant, and Mill, as well as of contemporary writers are examined. The course will also examine philosophical issues that arise in particular areas of mathematics such as probability theory and geometry. Instructor: Hitchcock.

H/HPS 129. History of Satellites: From Sputnik to Starlink. *9 units (3-0-6);* For course description, see History

H/HPS 130. Critical Infrastructures. *9 units (3-0-6);* For course description, see History

H/HPS 131. History of Extinction. *9 units (3-0-6);* For course description, see History

H/HPS 132. Humanistic Ecology. *9 units (3-0-6);* For course description, see History

H/HPS 133. Forests and Humans. *9 units (3-0-6);* For course description, see History

H/HPS 134. Birds, Evolution, Speciation and Society. *9 units (3-0-6);* For course description, see History

HPS/PI 136. Happiness and the Good Life. *9 units (3-0-6); first term.* This course will critically examine the emerging science of happiness and positive psychology, its philosophical assumptions, methodology, and its role in framing social policy and practice. Topics to be addressed include: the relation between happiness as subjective well-being or life satisfaction and philosophical visions of the good life; the relation between happiness and virtue; the causes of happiness and the role of life experience; happiness and economic notions of human welfare, attempts to measure happiness, and the prospect for an economics of happiness; happiness as a brain state and whether brain science can illuminate the nature of happiness; mental illness and psychiatry in light of positive psychology. Instructor: Quartz.

HPS/PI 138. Human Nature and Society. *9 units (3-0-6); second term.* This course will investigate how assumptions about human nature shape political philosophy, social institutions, and social policy. The course will begin with a historical perspective, examining the work of such political philosophers as Plato, Locke, Rousseau, and Marx, along with such psychologists as Freud and Skinner. Against this historical perspective, it

will then turn to examine contemporary views on human nature from cognitive neuroscience and evolutionary psychology and explore their potential implications for political philosophy and social policy. Among topics to be discussed will be the nature of human sociality and cooperation; economic systems and assumptions regarding production and consumption; and propaganda, marketing, and manipulation. Instructor: Quartz.

HPS/PI 139. Human Nature, Welfare, & Sustainability. *9 units (3-0-6); first term.* Policy makers since at least the time of Jeremy Bentham have argued that welfare maximization ought to be the goal of social policy. When this includes perfectionist notions of realizing one's capacities, economic prosperity, prosocial norms, and democratization have all coincided as key drivers of human development. Although the UN 2030 Agenda for Sustainable Development envisions worldwide inclusive and sustainable economic growth, there is substantial debate regarding the extent to which sustainability and economic growth are compatible. This course will critically examine the links between human welfare, economic growth, and material culture to better understand why economic growth and welfare have been taken to be intertwined - and the extent to which they could be decoupled. Our starting point will be the Brundtland report, its conception of welfare based on human needs, and subsequent articulations of needs-based theories of human welfare, including evolutionary and biological accounts that include social comparison processes such as esteem, status, and recognition. This will provide us with a theoretical framework for investigating the role of material culture in satisfying these needs and whether they may be satisfied by less resource-intense routes. Not offered 2025-26.

H/HPS 153. Inequality and Environment. *9 units (3-0-6);* For course description, see History

H/HPS 154. Feminist Science Studies. *9 units (3-0-6);* For course description, see History

H/HPS 155. Mortality Crises and Social Change: Epidemic Disease from 1300 to the Present. *9 units (3-0-6);* For course description, see History

HPS/H 160. Einstein on the Run: European Scientists Fleeing Fascism, War, and the Holocaust. *9 units (3-0-6); first term.* Structured around the life and work of Albert Einstein (1879-1955), the course will focus on the 1930s and 1940s, including the discovery of nuclear fission and the making of the atom bomb. Colleagues of Einstein, such as Max Born, Hans Bethe, Enrico Fermi, Lise Meitner, Erwin Schrodinger, and untold numbers of students, scientists, and engineers were forced out of their universities and laboratories by the rise of Fascism in Europe and sought shelter in the United States and elsewhere. Many contributed to the Allied World War II effort. Einstein himself became a facilitator for immigrant scientists, intellectuals, and artists seeking refuge. We shall use historical documents from the Einstein Archives to understand the

complex collective and individual experiences and their impact on developments in science and technology during this turbulent historical period. Instructor: Kormos-Buchwald.

HPS/H 162. Social Studies of Science. *9 units (3-0-6); third term.* A comparative, multidisciplinary course that examines the practice of science in a variety of locales, using methods from the history, sociology, and anthropology of scientific knowledge. Topics covered include the high-energy particle laboratory as compared with a biological one; Western as compared to non-Western scientific reasoning; the use of visualization techniques in science from their inception to virtual reality; gender in science; and other topics. Instructor: Feingold.

HPS/Pl 165. Selected Topics in Philosophy of Science. *9 units (3-0-6); Offered by announcement.* This is an advanced humanities course on a specialized topic in HPS and Philosophy. It is usually taught by new or visiting faculty. The course may be re-taken for credit except as noted in the course announcement. Limited to 15 students. See registrar's announcement for details. Instructors: Staff, visiting lecturers.

HPS/H 166. Historical Perspectives on the Relations between Science and Religion. *9 units (3-0-6); second term.* The course develops a framework for understanding the changing relations between science and religion in Western culture since antiquity. Focus will be on the ways in which the conceptual, personal, and social boundaries between the two domains have been reshaped over the centuries. Questions to be addressed include the extent to which a particular religious doctrine was more or less amenable to scientific work in a given period, how scientific activity carved an autonomous domain, and the roles played by scientific activity in the overall process of secularization. Instructor: Feingold.

HPS/H 167. Experimenting with History/Historic Experiment. *9 units (3-0-6); third term. Prerequisites: Ph 1 abc, and Ph 2 abc (may be taken concurrently).* This course uses a combination of lectures with hands-on laboratory work to bring out the methods, techniques, and knowledge that were involved in building and conducting historical experiments. We will connect our laboratory work with the debates and claims made by the original discoverers, asking such questions as how experimental facts have been connected to theories, how anomalies arise and are handled, and what sorts of conditions make historically for good data. Typical experiments might include investigations of refraction, laws of electric force, interference of polarized light, electromagnetic induction, or resonating circuits and electric waves. We will reconstruct instrumentation and experimental apparatus based on a close reading of original sources. Not offered 2025-26.

HPS/H 168. History of Electromagnetism and Heat Science. *9 units (3-0-6); second term. Prerequisites: Ph 1 abc, and Ph 2 abc (may be taken concurrently).* This course covers the development of electromagnetism and thermal science from its beginnings in the early 18th century through the early 20th century. Topics covered include

electrostatics, magnetostatics, electrodynamics, Maxwell's field theory, the first and second laws of thermodynamics, and statistical mechanics as well as related experimental discoveries. Not offered 2025-26.

HPS/H 169. Selected Topics in the History of Science and Technology. *9 units (3-0-6);* This is an advanced humanities course on a specialized topic in HPS and History. It is usually taught by new or visiting faculty. The course may be re-taken for credit except as noted in the course announcement. Limited to 15 students. See registrar's announcement for details. Instructors: Staff, visiting lecturers.

HPS/H 170. History of Light from Antiquity to the 20th Century. *9 units (3-0-6); first term. Prerequisites: Ph 1 abc, and Ph 2 abc (may be taken concurrently).* A study of the experimental, mathematical, and theoretical developments concerning light, from the time of Ptolemy in the 2nd century A.D. to the production of electromagnetic optics in the 20th century. Instructor: Buchwald.

HPS/H 171. History of Mechanics from Galileo through Euler. *9 units (3-0-6); Prerequisites: Ph 1 abc, and Ph 2 abc (may be taken concurrently).* This course covers developments in mechanics, as well as related aspects of mathematics and models of nature, from just before the time of Galileo through the middle of the 18th century, which saw the creation of fluid and rotational dynamics in the hands of Euler and others. Not offered 2025-26.

HPS/H 172. History of Mathematics: A Global View with Close-ups. *9 units (3-0-6); offered by announcement.* The course will provide students with a brief yet adequate survey of the history of mathematics, characterizing the main developments and placing these in their chronological, cultural, and scientific contexts. A more detailed study of a few themes, such as Archimedes' approach to infinite processes, the changing meanings of "analysis" in mathematics, Descartes' analytic geometry, and the axiomatization of geometry c. 1900; students' input in the choice of these themes will be welcomed. Not offered 2025-26.

HPS/H 175. Matter, Motion, and Force: Physical Astronomy from Ptolemy to Newton. *9 units (3-0-6); second term.* The course will examine how elements of knowledge that evolved against significantly different cultural and religious backgrounds motivated the great scientific revolution of the 17th century. Not offered 2025-26.

HPS/H 180. Forbidden Knowledge. *9 units (3-0-6); first term.* Why does the notion of freedom of knowledge and teaching in science and engineering matter? What kinds of restrictions have been placed on scientists and engineers, their publications and institutions? Who restrained scientific and engineering knowledge of what sorts; for what reasons; and how successfully? These questions will be addressed by exploring the strategies developed by the U.S. research community to protect the international circulation of knowledge after World War II, when scientific freedom and the export of technical data had to be

balanced with the needs of national security. Case studies will include the atomic bomb, the semiconductor industry in the 1970s and space technologies, notably rockets/missiles, in the 1990s. The threat to U.S. economics and military security posed by the Soviet Union in the Cold War, and by China today, has transformed the practice of research in university and in industry alike building new walls around the production and circulation of knowledge to affirm national sovereignty that is, all the while, being undermined by the global circulation of trained scientists and engineers. Not offered 2025-26.

PI/HPS 183. Bioethics. *9 units (3-0-6);* For course description, see Philosophy

H/HPS/VC 185. Angels and Monsters: Cosmology, Anthropology, and the Ends of the World. *9 units (3-0-6);* For course description, see History

H/HPS/VC 186. From Plato to Pluto: Maps, Exploration and Culture from Antiquity to the Present. *9 units (3-0-6);* For course description, see History

HUMANITIES

Hum/H 1. The Classical and Medieval Worlds. *9 units (3-0-6); first, second terms.* This course will survey the evolution of Mediterranean and European civilization from antiquity through the end of the Middle Ages. It will emphasize the reading and discussion of primary sources, especially but not exclusively literary works, against the backdrop of the broad historical narrative of the periods. The readings will present students with the essential characteristics of various ancient and medieval societies and give students access to those societies' cultural assumptions and perceptions of change. Not offered 2025-26.

Hum/H 2. Freedom Dreams: African American Visions of Liberation Since Emancipation. *9 units (3-0-6); first term.* Over the course of their history in the United States, African Americans have advanced various visions of liberation and strategies for attaining it. This course will examine how African Americans have conceptualized and sought to realize their freedom dreams since the end of chattel slavery. We will focus, in particular, on visions of freedom considered radical or utopian, both in their contemporary moment and in our present. Investigating how African Americans have imagined freer lives beyond their own localities, beyond U.S. borders, and even beyond Earth, our topics of discussion in the course may include emigration movements, black communism, pan-Africanism, black feminism, cults, Afrofuturism, hip hop culture, and abolitionism. Not offered 2025-26.

Hum/H 3. The United States in the Twentieth Century. *9 units (3-0-6); first term.* Designed to introduce students to the academic study of

history, this course examines key issues and events that shaped the political, social, and cultural history of the United States in the Twentieth Century. Through a wide variety of historical sources-including primary documents, fiction, and music-students will explore issues such as popular culture, immigration and labor, the civil rights movement, political realignment, and American intervention abroad. Not offered 2025-26.

Hum/H 5. The History of the Chinese Empire. *9 units (3-0-6); first, second terms.* This class will explore several facets of how the concept of empire and its historical formation in China was defined, portrayed, and developed over time. It offers students a chance to reflect on the interaction of event, record, and remembrance as these components combine in the creation and contestation of history. This course will particularly emphasize how the making, writing, and remembering of history responds to the advent of different regimes of legitimacy in order to give students a new perspective on the relationship between action, authorship, and interpretation in history. Not offered 2025-26.

Hum/H 6. Civilization, Science, and Archaeology: The Development of Science from Babylon through the Renaissance. *9 units (3-0-6); first term.* Connections in antiquity between astrology and astronomy, early theories of light, Islamic science, new concepts of knowledge during the European Middle Ages and Renaissance, the early laboratory, the development of linear perspective, the origins of the Copernican and Keplerian systems of astronomy, and the science of Galileo. Instructor: Buchwald.

Hum/H 7. Civilization, Science, and Archaeology: The Nature of Religious Belief in Ancient Egypt, Mesopotamia, and Israel. *9 units (3-0-6); second, third terms.* The civilizations of Egypt and Mesopotamia gave rise to complex forms of religious practices connected to the social order, moral behavior, and the afterlife. The course examines the origins of concepts of moral death and of sin as a violation of cosmic order in antiquity, the nature of polytheism, and the manner in which monotheism arose out of it. In addition to historical analyses the course includes readings by anthropologists who have studied cult structures as well as contemporary theories by evolutionary psychologists. Not offered 2025-26.

Hum/H 8. Civilization, Science, and Archaeology: Before Greece: The Origins of Civilization in Mesopotamia. *9 units (3-0-6); second, third terms.* This course will introduce students to the early development of civilization in Mesopotamia and Egypt from 4000 B.C.E. through 1000 B.C.E. Origins of agriculture and writing, the evolution of the city, and the structures of the Mesopotamian economy and social order will be discussed. Comparison with contemporary developments in Egypt during the Old and Middle Kingdoms may include a reading of Gilgamesh from 3000 B.C.E. and of the Egyptian Tale of Sinuhe. The course concludes with a discussion of life during the late Bronze Age. Focus will be on life as it was lived and experienced by many groups in

pre-classical antiquity rather than on kings and dynasties. Not offered 2025-26.

Hum/H 9. Europe Transformed. *9 units (3-0-6); third term.* Will introduce students to major aspects of the politics and culture of modernity that have profoundly transformed Western society and consciousness from the French Revolution to the contemporary era. A variety of historical, literary, and artistic works will be used to illuminate major social, intellectual, and cultural movements. The focus will be on significant and wide-ranging historical change (e.g., the industrial revolution, imperialism, socialism, fascism); on cultural innovation (e.g., modernism, impressionism, cubism); and on the work of significant thinkers. Not offered 2025-26.

Hum/H 10. Medieval Europe: The Problem of Violence. *9 units (3-0-6); first, second terms.* This course will explore how people understood violence in Europe between ca. 500 and ca. 1400 AD. It will focus on the various norms that governed the use of violence in a period when the right of free people to carry and use weapons was considered self-evident. Working through primary sources, students will explore the relationship between violence and vengeance, the law, central authority and public order, religion, emotions, public ritual, and economics. As they go along students will consider whether violence can coexist with or even promote stable, ordered societies, or whether it by definition creates disorder. Instructor: Brown.

Hum/H 11. Love and Death: Using Demography to Study the History of Europe from 1700. *9 units (3-0-6); first, third terms.* Demographic events-births, marriages, deaths-have always been highly responsive to changes in the local environment. Decisions about when to marry, how many children to have, or what kind of household to live in have always been closely correlated to decisions people take in other areas of their lives and, as a result, can tell us a great deal about the economic, social, and cultural worlds people inhabit. This course examines differences in demographic trends in Europe across space and time, from 1700 to the present, as well as existing explanations for these differences, including political economic factors, social and cultural norms, biology and disease environments. Some topics include: the demographic effects of war, industrialization, and urbanization; changes related to the emergence of reliable contraceptive technologies; changes related to the expansion of economic opportunities for women; the effects of government policies on demographic decisions. Not offered 2025-26.

Hum/H 12. Social Theory. *9 units (3-0-6); first term.* This course introduces students to both canonical and non-canonical theories of society. From the formative debates over the role of the state in human affairs in early modern Europe to radical interpretations of social good in the twentieth century, students will be exposed to competing theories of society and their implications in the political, the economic, the emotional, and the scientific realms. By the end of the quarter, students will be able to link contemporary notions of individuality, agency,

rationality, morality, and ethics to divergent discourses in the history of social theory. Not offered 2025-26.

Hum/H 13. Brave New Worlds: Race, Human Rights and the Age of Discovery. *9 units (3-0-6); second, third term.* This course traces the origins of modern racism and, perhaps surprisingly, of human rights advocacy itself, to a seminal moment in global history sometimes called the Age of Discovery. At this time, two small European kingdoms, Spain and Portugal, first conducted trade and conquest in Atlantic Africa, the Americas, and the Indian and Pacific Oceans, forging the world's first truly global empires. We study the legacy of racism and humanitarianism in eye-witness accounts, maps, images and other materials attesting to Spain's seminal encounters with the Americas. Instructor: Wey-Gomez.

Hum/H/HPS 14. Race, Science, and Medicine in U.S. History. *9 units (3-0-6); second term.* This course will explore how natural philosophers and scientists have defined, used, and sometimes challenged ideas about race from the eighteenth century to today. Using a range of primary and secondary sources, we will examine how scientific ideas about race developed in concert with European imperial expansion and slavery; how these ideas were employed in legal cases, medical practice, and eugenics policies; and how activists and scholars have challenged racist practices and ideas. Finally, we will turn to the recent resurgence of racial thinking in biology and medicine in the light of the history of race and science. Not offered 2025-26.

Hum/H/HPS 15. Waste in the World. *9 units (3-0-6); second, third terms.* The things that human beings make and throw away rarely stay where we put them. Just as humans have shaped the biological and physical world, the biological and physical world shapes human actions. In this course, we will examine how these interacting forces propel environmental and cultural change. We will explore these concepts through the lens of waste - how different groups at different points in history define waste, where discarded things go and what they become as they move through space and time. We will consider how conflicting perceptions of utility and waste in different cultural and historical contexts have factored into shifting ideas about race, class, gender, wilderness, technology, consumption, and sovereignty. In rethinking waste, we will explore the multiple meanings of "nature," assess the roots of sustainability, and evaluate past events in light of current ideas about environmental justice. While this course prioritizes reading and discussion, we will also engage with the world around us through visual analysis. Pasadena and Los Angeles will be among our most important resources, allowing us to ground global ideas in a local context. Not offered 2025-26.

Hum/H 16. Environment and Environmental Expertise in Premodern World. *9 units (3-0-6); third term.* This course offers an introduction to environmental history with a particular focus on the field's intersection with the histories of science and knowledge. We will discuss how historians write about the environment in the past, how they approach

the interactions of states and societies with the environment, as well as examining what and how people in the past knew about their environments. The course will stretch chronologically and geographically and cover a broad range of topics from Graeco-Roman Antiquity in the Mediterranean, through the early modern Atlantic world, to the early nineteenth-century United States. We will examine people's interactions with climate, forests, waterways, wildlife, and natural disasters, to name just a few themes, and learn how societies understood, described, and managed the natural world in premodern times. Instructor: Falkowski.

Hum/H 17. Vast Early America. *9 units (3-0-6); first, second term.* Traditional histories of the United States usually begin with the so-called original Thirteen Colonies-the British territories that eventually banded together and formed the early United States. But these colonies comprised only a small sliver of North America, which was (and is) an expansive, dynamic, and diverse place. This course focuses on that larger history and on the complex and sometimes violent meetings of a variety of different cultures, peoples, and environments that happened in North America between 1450 and 1850. Topics will include the histories of Indigenous peoples, enslaved Africans, and women; the meeting of different European empires; the movement of plants, animals, and microbes between continents; the relationship between different North American regions like the Caribbean, Southwest, and Northeast. This course will also explore the relationship between historic events and the national mythology of United States and ask students to reflect on why early American history matters in the present day. Instructor: Jones.

Hum/H/HPS 18. Introduction to the History of Science. *9 units (3-0-6); second, third terms.* Major topics include the following: What are the origins of modern Western science, when did it emerge as distinct from philosophy and other cultural and intellectual productions, and what are its distinguishing features? When and how did observation, experiment, quantification, and precision enter the practice of science? What were some of the major turning points in the history of science? What is the changing role of science and technology? Using primary and secondary sources, students will take up significant topics in the history of science, from ancient Greek science to the 20th-century revolution in physics, biology, and technology. Hum/H/HPS 10 may be taken for credit toward the additional 36-unit HSS requirement by HPS majors and minors who have already fulfilled their first-year humanities requirement and counts as a history course in satisfying the first-year humanities breadth requirement. Instructor: Feingold.

Hum/H 19. Righting the Wrongs of History. *9 units (3-0-6); third term.* In recent years, growing numbers of people committed to equity and social justice have discussed various ways of addressing historical injustices whose harms are still experienced in the present. Some have proposed monetary restitution and other restorative strategies that account for resources, opportunities, and lives lost. Others have advocated more symbolic reparative approaches that seek to heal the psychic wounds of injustice. This course will examine efforts to right the wrongs of history,

with particular attention given to the decades-long movement for reparations for African Americans and recent efforts to address difficult histories at Caltech. Investigating initiatives that have been realized and others that have been only imagined, in this course we will seek to understand both the possibilities and impossibilities of repairing historical harms. Not offered 2025-26.

Hum/H/HPS 20. COVID-19 and Other Pandemics: Science, Medicine, and Public Controversies. *9 units (3-0-6); first term.* This course will analyze the COVID-19 pandemic in the context of other similar events in the history of public health and medicine. How do we understand the COVID pandemic and the differential responses to it around the globe? What is the best framework for proper understanding? Science, history, politics, culture? Special attention will be given to the state of medical science today and in the past, the understanding of ethology, transmission, and symptoms; the role of scientists, physicians, and "quacks"; the persistence and change in the forms of fear, superstition, and misinformation across time. Instructor: Kormos-Buchwald.

Hum/En 21. Monsters and Marvels. *9 units (3-0-6); second, third terms.* Marvels flourish at the boundaries of literary invention, religious belief, and scientific inquiry, challenging assumptions about natural processes and expected outcomes. From Grendel, the monstrous foe of Beowulf, to Satan, Milton's charismatic antihero, this seminar examines the uses of the marvelous in a variety of texts and genres, including Shakespearian drama, medieval romance, and early travel-writing. Readings may include Beowulf, Marie de France, Chaucer, John Mandeville, Shakespeare, Milton. Not offered 2025-26.

Hum/En 22. Inequality. *9 units (3-0-6); third term.* This class studies a sample group of social hierarchies and explores whether they are natural or artificial, real or perceived, just or unjust. Topics from past years have included covid-19 vaccine inequality; IT worker inequality; happiness inequality; animal inequality; and inequality between humans and generative AI chatbots. We will treat the idea of inequality not as an abstract concept but as a heuristic question that can help us compare and analyze concrete readings. Instructor: Haugen.

Hum/En 23. Literature and Medicine. *9 units (3-0-6); third term.* The relationship between patients and doctors, the ill and the well, involves a constant exchange of stories. In this course we will look more closely at the relationship between medicine and narrative through a selection of fiction, essays and poems that investigate the interplay between doubt and diagnosis, the idea of the case study, the problem of medical responsibility, and the language of pain and illness. Authors covered may include Sontag, Mantel, Conan Doyle, Freud, Woolf, Dickinson, Ishiguro and Shelley. Not offered 2025-26.

Hum/En 24. The Scientific Imagination in English Literature. *9 units (3-0-6); first term.* This course considers three periods of major scientific development-the Renaissance, the nineteenth century, and the modern

period- to explore the influence new ideas, discoveries, and theories had on the imagination of English writers. We will look at the early modern interplay between magic and science, Romantic and Victorian debates about evolution, and the twentieth-century advent of modern physics as we confront consistent tropes like the mad scientist, the scientist-hero, and the problem of uncertainty. Authors covered may include Shakespeare, Marlowe, Bacon, Shelley, Darwin, Conan Doyle, Stevenson, Auden, McEwan, and Stoppard. Not offered 2025-26.

Hum/En 25. The Human Animal. *9 units (3-0-6); first term.* European literature has long been a testing ground for radical new ideas which have come to shape our basic understanding of what it means to be a thinking, speaking and perhaps even autonomous human being. The question of what - if anything - makes us different from animals was debated from numerous points of view: including talking dogs, philosophizing women, bestial men, humanlike beasts, and other creatures that defied the conventions of the time. This course explores some of the key literary texts that shaped this debate and pays careful attention to their cultural environments. Selected readings from Cervantes, La Fontaine, Swift, Rousseau, Buffon, Aikin, and Wollstonecraft, among others. Instructor: Holland.

Hum/En 26. What Is Imagination?. *9 units (3-0-6); third term.* Albert Einstein once said that imagination is everything, and even more important than knowledge. This course invites you to think about - and use - your imagination as we explore how the act of imagining has been viewed over time in the service of memory and creativity, in both the arts and the sciences. Readings will focus on the eighteenth and nineteenth centuries and will include Hume, Moritz, Kant, Novalis, Hoffmann, Coleridge, and Wordsworth. Not offered 2025-26.

Hum/En 27. Introduction to the Modern Novel. *9 units (3-0-6); third term.* This course is an introduction to the study of the contemporary novel in English. We will explore the value of reading novels both for their own sake and for what they might tell us about the history, culture, and politics of the contemporary English language. We will read around three novels from the twenty-first century, along with relevant essays, keywords, and short stories. Authors read may include Zadie Smith, Bernadine Evaristo, Angie Cruz, Tommy Orange, Julie Buntin, Akwaeke Emezi, and Ocean Vuong. Not offered 2025-26.

Hum/En 28. Telling Time in American Modernism. *9 units (3-0-6); first term.* This course will explore modernist literature's relationship to time. We will identify the methods that modernist narratives use to characterize the experience of lived time, or temporality, such as stream of consciousness, non-linear storytelling, and narrative omissions. We will ask: what challenges does temporal experience pose to clock time and, more broadly, historical time? The course will emphasize the influence of new technologies on modernist representations of time and space, including rural and urban space, and modernism's engagement with changing attitudes regarding race, gender and sexuality. Students

will learn about key movements within American modernism, including the Harlem Renaissance, and may opt to analyze modernist literature's relationships to other genres, including music and visual culture. Not offered 2025-26. .

Hum/En 29. Dream Narratives. *9 units (3-0-6); third term.* Dream narratives reveal as much about cultural beliefs and superstitions as they do about techniques of narration and interpretation. This course investigates key developments in the literature on dreams and dream interpretations with examples drawn from the Renaissance through the beginning of the nineteenth century. Selected readings from Boccaccio, Descartes, Calderón, Shakespeare, and Diderot, among others. Not offered 2025-26.

Hum/En 30. Reading Animals. *9 units (3-0-6); first term.* In this course we will look closely at representations of nonhuman animals in literature from the Middle Ages to our present moment as opportunities to revisit definitions of, and the boundaries created and blurred between, the "human" and the "animal." Readings may include Marie de France, Marianne Moore, Franz Kafka, Donna Haraway, Donika Kelly, and K-Ming Chang. Not offered 2025-26.

Hum/En 31. Introduction to Black Literature and Culture in the United States. *9 units (3-0-6); second term.* This introductory humanities course is for anyone who wishes to celebrate, study, and pass on Black expressive culture to the next generation. Altogether, the course will be an in-depth introduction to the study of Black intersectional identities and lived experiences across the United States. Our texts will be comprised of a variety of artistic, cultural, and literary works in the US created since before its founding up until today. In addition to reading several literary texts, students will have the opportunity to learn about several works of cultural expression that have become beloved touchstones in Black history. Students will also read and apply several critical contexts and methodologies for the study of Black literature and culture and will regularly document their own goals for furthering this body of work for future scholars. Not offered 2025-26.

Hum/En 32. The Origins of Science Fiction: Fictions about Science. *9 units (3-0-6); third term.* This course considers a set of classic, often-adapted nineteenth-century literary works that helped to pave the way for modern "science fiction," and that simultaneously supplied us with many forms and terms we still use for imagining the monstrous and the horrifying. Why does the depiction of scientific work and scientists so often shade into the terrain of nightmare in fiction? What separates the "mad scientist" from the ambitious scientist? How and why do the literary inventions of the past still resonate in the present? Works considered may include: Frankenstein, The Strange Case of Dr. Jekyll and Mr. Hyde, Dracula, The Island of Doctor Moreau, The Coming Race. Instructor: Gilmore.

Hum/En 33. Modern Metamorphoses. *9 units (3-0-6); second term.* Narratives of metamorphosis have traditionally used their dramatic subject matter-a radical change of form-as a vehicle for social criticism. This course explores the ways in which twentieth-century writers experiment with the concept of metamorphosis to take on the most pressing political and social issues of their day, including slavery, women's rights, and critiques of capitalist excess. Readings to include Kafka, Garnett, Orwell, Tawada, and Erpenbeck. Not offered 2025-26.

Hum/En 34. Literature and Deception. *9 units (3-0-6); second term.* In this course, we will be considering lying and other types of deception from the point of view of literature and philosophy, with two main goals in mind: 1) to compare cultural practices of deception at various times in European history and 2) to think in general terms about the ability of a literary text to convey truth and falsehood. Can a fictional text be "true" in any meaningful sense, such as a political one? Or, as many people have thought over time, is it more accurate to think about literature as a beautiful lie? Readings will include the legend of Till Eulenspiegel as well as texts by Machiavelli, Shakespeare, Diderot, and those relating to the Ossian controversy. Not offered 2025-26.

Hum/En 35. Masterworks of Contemporary Latin American Fiction. *9 units (3-0-6); second, third term.* This course studies Latin America's most influential authors in the 20th and 21st centuries, with a focus on short stories and novellas produced by the region's avant-garde and "boom" generations. Authors may include Allende, Bombal, Borges, Garcia Marquez, Quiroga, Poniatowska, and Vargas Llosa. All readings and discussions are in English. Not offered 2025-26. Instructor: Wey-Gomez.

Hum/En 36. American Literature and Culture. *9 units (3-0-6); first, third term.* Studies of American aesthetics, genres, and ideas from the birth of the nation to the present. Students will be introduced to the techniques of formal analysis. We will consider what constitutes evidence in relation to texts and how to develop a persuasive interpretation. Topics may include Nature's Nation, slavery and its aftermath, individualism and the marketplace, the "New Woman," and the relation between word and image. Instructor: Weinstein.

Hum/En 37. Welcome to Dystopia. *9 units (3-0-6); first.* This course surveys a number of literary destinations you would never want to visit in real life: places with near-unsurmountable political and environmental threats where individuality is crushed and where happy endings are hard to come by. Given that life in a dystopia is so awful, what makes this genre of fiction so popular? And what can fictional dystopian societies teach us about our own? We will look for answers to these questions in the work of some of the greatest writers of the past century, including Franz Kafka, Shirley Jackson, Philip K. Dick, Cormac McCarthy, and Ursula K. Le Guin, among others. Not offered 2025-26. .

Hum/H 38. Leonardo da Vinci & Co.: How to Understand Technological Invention in the Long Renaissance. *9 units (3-0-6); second term.* How do we understand technology? How do we define technological invention? How does technological innovation circulate? This course explores major technological achievements across different historical contexts, with a particular focus on the Mediterranean world between the 14th and 17th centuries. It also examines processes of technological transfer among Asia, Europe, Africa, and the Americas. We will investigate how technological innovations emerged, circulated, interacted, and shaped societies-as well as new ideas in science. Analyzing the concept of invention will be especially useful in critically assessing traditional narratives of rupture-such as the Renaissance and the Scientific Revolution-as well as narratives of continuity in the development of scientific knowledge and technology. Students will take part in collaborative projects, including 3D-printing historical tools and machines. They will also work with sources from special collections in libraries, museums, and archives. Instructor: Zanetti.

Hum/En 39. The Ethics of Friendship. *9 units (3-0-6); second term.* Is there such a thing as an ideal friend? What responsibilities do friends have to each other? How can friendship negotiate differences, and what are its limits? To explore these enduring questions, we will read classical and Renaissance philosophies of the nature of friendship as well as imaginative literature from Miguel de Cervantes to Toni Morrison that puts these theories to the test. Students will gain a deeper understanding of views on friendship across the centuries, including the challenges and the rewards of working towards becoming a better friend. Meanwhile, the course's assignments aim to make you a stronger reader and writer. Students will develop skills in how to analyze difficult texts from various historical periods and craft persuasive arguments about them. Authors read will include Aristotle, Cicero, Montaigne, Shakespeare, Cervantes, Shelley, and Morrison. Instructor: Morstein.

Hum/Pl 40. Right and Wrong. *9 units (3-0-6); first, second terms.* This course addresses questions such as: Where do our moral ideas come from? What justifies them? How should they guide our conduct, as individuals and as a society? What kind of person should one aspire to be? Topics the course may deal with include meta-ethical issues (e.g., What makes an action right or wrong? When is one morally responsible for one's actions? How should society be organized?) and normative questions (e.g., Is eating meat morally acceptable? What should we tolerate and why? What are society's obligations toward the poor?). In addition, the psychological and neural substrates of moral judgment and decision making may be explored. The course draws on a variety of sources, including selections from the great works of moral and political philosophy (e.g., Aristotle's Nichomachean Ethics, Hobbes's Leviathan, Kant's Groundings for a Metaphysics of Morals, and Rawls's A Theory of Justice), contemporary discussions of particular moral issues, and the science of moral thought. Instructor: Quartz.

Hum/Pl 41. Knowledge and Reality. *9 units (3-0-6); third term.* The theme of this course is the scope and limitations of rational belief and knowledge. Students will examine the nature of reality, the nature of the self, the nature of knowledge, and how we learn about the natural world. Students will be introduced to these issues through selections from some of the world's greatest philosophical works, including Descartes's Meditations, Pascal's Pensées, Hume's Enquiry Concerning Human Understanding, Berkeley's Principles of Human Knowledge, and Kant's Prolegomena to any Future Metaphysics. A variety of more contemporary readings will also be assigned. Instructor: Hitchcock.

Hum/En 42. Climate Fiction. *9 units (3-0-6); first term.* Climate change is a narrative as well as a planetary crisis-it transforms the stories we tell about our world. In this class, we will look at works of fiction that speculate on the shifting relationships between humans, society, and the environment, offering both hopeful and sobering possibilities. Through classic and more recent works of climate fiction, or cli-fi, we will explore the dynamics of resilience and vulnerability, hope and fear, that inform the contemporary environmental imagination. Expect readings from authors such as Ursula K. Le Guin, Ernest Callenbach, Octavia E. Butler, Amitav Ghosh, and Kim Stanley Robinson. Instructor: Earhart.

Hum/En 43. Nature Writing. *9 units (3-0-6); third term.* Cultural theorist Raymond Williams once said that nature is "perhaps the most complex word in the language." And yet, when we think of nature, certain images probably come to mind-from oceans and rivers to forests and mountain peaks. Here, we will engage a long arc of environmental writing in the United States to investigate the conventions and contradictions of the "natural world." We will consider Transcendentalist and early environmentalist literature, as well as contemporary critiques of the nature-society divide, particularly as it relates to questions of race, class, and gender. Authors include Henry David Thoreau, Aldo Leopold, Rachel Carson, Leslie Marmon Silko, and Lauret Savoy, among others. Instructor: Earhart.

Hum/Pl 44. Philosophy Through Science Fiction. *9 units (3-0-6); first term.* This course will provide a broad introduction to philosophy using examples from science fiction to make abstract philosophical problems vivid. Topics may include: time travel and the reality of the past and future; teleportation and what makes someone the same person over time; fictional tales of extended deception and Cartesian skepticism; futuristic utopias and the question of what make a life good; the moral status of aliens and animals; intelligent robots and the relation between mind and body; parallel universes and the philosophical foundations of quantum physics. Instructor: Sebens.

Hum/Pl 45. Ethics & AI. *9 units (3-0-6); second term.* How do we reconcile the possibilities of modern machine learning with ethical and moral demands of fairness, accountability and transparency? This course will take a case study-based approach to the challenges at the interface of algorithms and human values. By exploring existing debates

on algorithmic bias, explainable AI and data ownership, students will be exposed to the relevance of ethical systems of thought to modern social questions. Instructor: Eberhardt.

Hum/En 46. Race and Labor in Modern American Literature. *9 units (3-0-6); third term.* Mass immigration and the abolition of slavery transformed the nature of the American workforce in the 19th century. Since then, American labor has been a key arena in which racial division and solidarity have been experienced and negotiated. How did racial hierarchies structure the everyday encounters and struggles of American workers? How did literary writers make sense of these tensions while imagining political alternatives? This class will provide a historical overview of how the interplay between race and labor was contested in 20th-century American literature. Authors covered may include Claude McKay, H. T. Tsiang, Muriel Rukeyser, Carlos Bulosan, and Gwendolyn Brooks. Instructor: Li.

Hum/H 47. Religion in America, from the Reformation to the Rapture. *9 units (3-0-6); first term.* This course is an introduction to the study of American religion, with a focus on how different groups and communities have practiced their faith in different eras. Starting with an overview of Reformation-era battles over doctrine and ritual, the course then considers Native, African, and European roots of colonial American religious culture; the legal and political history of church and state after the Revolution; the place of women in major religious traditions; the emergence in the U.S. of immigrant communities of believers representing the world's major religions in the 19th and 20th centuries; and contemporary battles over religion in public. Instructor: Juster.

Hum/VC 48. Ways of Seeing. *9 units (3-0-6); first term.* "The knowledge of photography is just as important as that of the alphabet," wrote artist László Moholy-Nagy in 1928. "The illiterate of the future," he warned, "will be the person ignorant of the use of the camera as well as the pen." Almost a century later, this pronouncement rings as true as ever in a world so profoundly shaped not just by photography but also films, advertisements, and video games, cartoons and comics, molecular graphics and visual models. In this course we will explore how visual culture shapes our lives and daily experiences, and we will learn to find wonder in its rich details. In doing so, we will develop the visual literacy that Moholy-Nagy envisioned: essential skills in reading, analyzing, discussing, and writing about visual materials and their circulation through the physical and virtual networks that structure our world. Instructor: Jacobson.

Hum/VC 49. Seeing Race. *9 units (3-0-6); second term.* From colorblind casting to racial profiling, visual culture is at the heart of contemporary conversations about race and racism. We are living in a moment where representations of racial differences are both highly visible and highly contested in art, popular culture, and mass media across the US and in many other parts of the world. Rather than treat these representations as reflections of reality, this course takes a critical look at the relationship

between visual culture and the production of (racialized) knowledge and situates this relationship in a broader global and historical context. We will consider how images shape our 'common sense' ideas about race and its intersections with ability, gender, and sexuality, and explore how race informs what - and how - we see. In addition to reading landmark literature by scholars like Frantz Fanon, bell hooks, Richard Dyer, Edward Said, and Jodi Byrd, students will engage with artists, filmmakers, and activists who work to dismantle what Nicholas Mirzoeff (2023) calls "white sight" or the distinctive ways of seeing that characterize white supremacy. Not offered 2025-26. .

Hum/VC 50. Introduction to Film. *9 units (3-0-6); first, third terms.* This course examines the historical development of film as a popular art and entertainment medium from the 1880s to the present, with a focus on the American and European contexts. Students will learn how to watch a film - how to pay attention to significant visual details and to the ways films construct meaning from the language of images - and will develop the skills to write fluently about what they see. The course covers some of the most influential genres and movements from the earliest actuality films, through the French New Wave, to the Disney/Marvel Universe. Films covered may include short comedies from Charlie Chaplin and Buster Keaton, *M*, *It Happened One Night*, *The Seven Samurai*, *The Battle of Algiers*, and *Black Panther*. Instructor: Jurca.

Hum/VC 51. Icons and Iconoclasm. *9 units (3-0-6); second term.* How does something - an image, a person, a thing, an idea - become iconic? Drawing from the worlds of art and film, advertising and PR, science and technology, politics and propaganda, this course explores what makes certain people, places, and things "icons." To do so, we will first deploy a range of methods for closely analyzing images as signs and symbols, including the practice art historians term "iconology." We will then examine histories of how objects have circulated through culture - from newspapers and magazines to postcards, jpegs, and memes - and thereby become ubiquitous features of everyday experience. Finally, we will consider iconoclasm, the destruction of icons, and the beliefs and logics behind powerful interdictions against visual representation. Students will leave the course with a stronger understanding of image power as well as foundational tools of visual and media literacy. Not offered 2025-26.

Hum/VC 52. Color. *9 units (3-0-6); second term.* This course will take us from the ancient caves of Indonesia to the caravan trades of Medieval Sahara, the mines of early modern Afghanistan, the codices of colonial Mexico City, the gardens of the Incan empire, the alchemical recipes of China, and, finally, the pink "rouge" makeup on the French queen Marie Antoinette's cheeks. We will examine color across geographies and cultures in history with a thematic approach, exploring each week a different facet of color as it relates to visual culture, art, and architecture: from environmental cultivation and extraction to alchemy, magic, chemistry, technology, commerce, anthropology, literature, physics, medicine, psychology, race studies, culture, and aesthetics. This class

will emphasize visual analysis, the reading of primary and secondary sources, and the crafting of original research and writing. We will have on-site visits to the Huntington Museum, Library, and Botanical Gardens, and discussions with contemporary color-makers and artists. Instructor: Linden.

Hum/H 53. The Early Islamic World (c. 600-1453). *9 units (3-0-6); third term.* In the middle of the seventh century, the tribal followers of a new religion called Islam burst out of the deserts of the Arabian Peninsula and rapidly overwhelmed the armies of the ancient Byzantine and Sassanid Empires. By the middle of the next century, they had conquered much of the western Eurasian world, from the Central Asian steppe to the Straits of Gibraltar. The Muslims' extraordinary achievement bound together lands formerly ruled by two ancient empires-the Roman and Persian-and transformed the cultures, societies, economies, and laws of the diverse peoples now subject to their rule. This course explores the political, social, and institutional history of the Islamicate world from its origins in seventh-century Arabia to the Ottoman conquest of Constantinople in 1453. It will pay particular attention to relations between Islam and the other cultures of the Mediterranean as they are revealed in episodes such as the conquest of Spain, the Crusades, and repeated conflicts with the Byzantine Empire. It will also explore internal political, cultural, and religious conflict among the followers of Islam themselves. Instructor: Morgan.

Hum/En 54. Introduction to English Renaissance Poetry. *9 units (3-0-6); second term.* This course will provide an introduction to English poetry in the 16th and 17th centuries, with an emphasis on exploring how poems served as vehicles to make sense of the political and social contradictions of early modern England. How do Sir Philip Sidney and William Shakespeare's sonnets blend themes of unrequited desire with political critique? How does Hester Pulter develop early ideas of physics through her lyrics, like imagining the apocalypse through the dissolution of atoms? Other authors covered in the course may include Katherine Philips, John Donne, Margaret Cavendish, and John Milton. Instructor: Li.

IC/Hum 55 abc. Integrated Core: Introduction to Energy Humanities. *3 units (1-0-2);* For course description, see Integrated Core

Hum/En 56. Special Topics in Humanities/English. *Units are by arrangement; Offered by announcement.* This course will count as a first-year humanities course in English. It is usually taught by new or visiting faculty. This course is not repeatable. Limited to 15 students. See registrar's announcement for details. Instructor: Staff.

Hum/H 57. Special Topics in Humanities/History. *Units are by arrangement; Offered by announcement.* This course will count as a first-year humanities course in history. It is usually taught by new or visiting faculty. This course is not repeatable. Limited to 15 students. See registrar's announcement for details. Instructor: Staff.

Hum/Pl 58. Special Topics in Humanities/Philosophy. *Units are by arrangement; Offered by announcement.* This course will count as a first-year humanities course in philosophy. It is usually taught by new or visiting faculty. This course is not repeatable. Limited to 15 students. See registrar's announcement for details. Instructor: Staff.

Hum 59. Special Topics in Humanities/Visual Culture. *9 units (3-0-6); offered by announcement.* This course will count as a first-year humanities course in visual culture. It is usually taught by new or visiting faculty. This course is not repeatable. Limited to 15 students. See registrar's announcement for details. Instructor: Staff.

Hum 75. Selected Topics in Humanities. *Variable units; offered by announcement.* A course on a specialized topic in some area of the humanities, usually taught by new or visiting faculty. Recent offerings have included courses on film-making, poetry writing, speculative fiction, and the difference between humans and other animals. The course may be re-taken for credit except as noted in the course announcement. Class size is normally limited to 8-15 students. See registrar's announcement for details. Instructors: Staff, visitors.

Hum 80. Frontiers in the Humanities. *1 unit (1-0-0); third term.* Weekly seminar by a member of the Caltech humanities faculty or a visitor to discuss a topic of their current research at an introductory level. The course can be used to learn more about different areas of study within the humanities. For those interested in (or who become interested) in pursuing a second option in the humanities, the course will introduce students to the kinds of research carried out by members of the humanities faculty and help them find faculty advisers. Not offered 2025-26.

Hum 105. Topics in French Literature. *9 units (3-0-6); second term. Prerequisites: L 103 abc or equivalent.* Hum 105 and Hum 116 are taught in alternate years. Topics may include the 20th-century major French novels; French modern theatre; conflicting memories of the second world war; coming of age novels; the French Muslim identity. Conducted in French. Students who write papers in French may enroll in this class as L 105. Instructor: Orcel.

Hum 114 abc. Spanish Language Literature and its Film Adaptations. *9 units (3-0-6); first, second, third terms. Prerequisites: L 112 abc or equivalent.* Offered concurrently with L 114abc. This course explores the mixed cultures of the Spanish speaking countries and the United States, through a compilation of novel excerpts, short stories, drama, music, poetry, and film. This heterogeneity of written and audiovisual texts aims to acquaint students with the rich cultures of the Spanish speaking peoples, from the standpoint of ethnicity, gender, and social class. The course also focuses on continuing to develop Spanish language skills. Conducted in Spanish. (a) The traditional role of women during dictatorships and their journey to freedom (b) Family relationships and

their impact on mental and physical health (c) building gender, social, and economic equality. Each term can be taken independently. Students who write papers in Spanish may enroll in this class as L 114. Instructor: Arjona.

Hum 115 abc. Hispanic Cultures in Film and Literature. *9 units (3-0-6); first, second, third terms. Prerequisites: L 112 abc or equivalent.* Offered concurrently with L 115. This course introduces students to narrative film and literature from the Hispanic world, with an emphasis on the hero figure. It also takes up hybridization and transculturation in the Americas, specifically in Mexico, Peru, and Cuba, as well as film and narratives of Spain from the Civil War to the present. Conducted in Spanish. (a) Basics of Hispanic films and narratives, and their socio-cultural roots (b) Hybridization and mestizo cultures in the Hispanic world (c) The last century in Hispanic film and narrative. Each term can be taken independently. Students who write papers in Spanish may enroll in this class as L 115. Not offered 2025-26.

Hum 116. Topics in French Culture. *9 units (3-0-6); second term. Prerequisites: L 103 abc or equivalent.* Offered concurrently with L 116. Hum 105 and Hum 116 given in alternate years. The course focuses on contemporary France. Topics may include France and the European Union; political parties and elections; family life; social protection; religion; education; media and technology. Conducted in French. Students who write papers in French may enroll in this class as L 116. Not offered 2025-26.

Hum 119. Selected Topics in Humanities. *Variable units; offered by announcement.* This is an advanced humanities course on a specialized topic in some area of the humanities. It is usually taught by new or visiting faculty. The course may be re-taken for credit except as noted in the course announcement. Limited to 15 students. See registrar's announcement for details. Instructors: Staff, visitors.

L/Hum 150. Japanese Literature in Translation. *9 units (3-0-6);* For course description, see Languages

L/Hum 151. Japanese Literature in Translation from Medieval to Pre-modern Japan. *9 units (3-0-6);* For course description, see Languages

L/Hum 152. Classical French Literature in Translation. *9 units (3-0-6);* For course description, see Languages

L/Hum 154. The Modern French Novel in Translation. *9 units (3-0-6);* For course description, see Languages

L/Hum 162. Spanish and Latin American Literature in Translation. *9 units (3-0-6);* For course description, see Languages

Hum 169. Chinese Cinema. *9 units (3-0-6); third term.* Offered concurrently with L 169. This course offers an overview of Chinese-language films from the early twentieth century to the present. We will view a selection of cinematic masterpieces and place each film in its historical context, considering both the aesthetic form and socio-cultural content of the film. Lecture topics include the Golden Ages of early Chinese cinema, Hong Kong New Wave, the Fifth Generation of Chinese filmmakers, Taiwan New Cinema, the Sixth Generation of Chinese filmmakers, Chinese animation, Asia-Pacific co-productions, and sci-fi movies. Students who write papers in Chinese may enroll in this class as L 169. This course can be repeated for credit when the course content changes. Instructor: Wang.

Hum 174. Topics in Masterpieces of Chinese Writing. *9 units (3-0-6); third term. Prerequisites: instructor's permission.* Offered concurrently with L 174. Reading and discussion of representative Chinese written work throughout Chinese history, including philosophical texts and literary works in different genres. Students are expected to examine these works in light of their sociopolitical and historical contexts. Students who write papers in Chinese may enroll in this class as L 174. This course can be repeated for credit when the course content changes. Instructor: Wang.

INFORMATION AND DATA SCIENCES

IDS 9. Introduction to Information and Data Systems Research. *1 unit (1-0-0); second term.* This course will introduce students to research areas in IDS through weekly overview talks by Caltech faculty and aimed at first-year undergraduates. Others may wish to take the course to gain an understanding of the scope of research in computer science. Graded pass/fail. Not offered 2025-26. Instructor: Staff.

ACM/IDS 101 ab. Methods of Applied Mathematics. *12 units (4-4-4);* For course description, see Applied & Computational Math

ACM/IDS 104. Applied Linear Algebra. *9 units (3-1-5);* For course description, see Applied & Computational Math

CMS/ACM/IDS 107 ab. Linear Analysis with Applications. *12 units (3-0-9);* For course description, see Computing and Mathematical Sciences

ACM/EE/IDS 116. Introduction to Probability Models. *9 units (3-1-5);* For course description, see Applied & Computational Math

CS/IDS 121. Relational Databases. *9 units (3-0-6);* For course description, see Computer Science

IDS/Ec/PS 126. Applied Data Analysis. *9 units (3-0-6); first term. Prerequisites: Ma 3/103 or ACM/EE/IDS 116, Ec 122 or IDS/ACM/CS 157 or Ma 112 a.* Fundamentally, this course is about making arguments with numbers and data. Data analysis for its own sake is often quite boring, but becomes crucial when it supports claims about the world. A convincing data analysis starts with the collection and cleaning of data, a thoughtful and reproducible statistical analysis of it, and the graphical presentation of the results. This course will provide students with the necessary practical skills, chiefly revolving around statistical computing, to conduct their own data analysis. This course is not an introduction to statistics or computer science. I assume that students are familiar with at least basic probability and statistical concepts up to and including regression. Instructor: Katz.

EE/Ma/CS/IDS 127. Error-Correcting Codes. *9 units (3-0-6);* For course description, see Electrical Engineering

EE/Ma/CS/IDS 136. Information Measures and Applications. *9 units (3-0-6);* For course description, see Electrical Engineering

CMS/CS/IDS 139. Analysis and Design of Algorithms. *12 units (3-0-9);* For course description, see Computing and Mathematical Sciences

Ma/ACM/IDS 140 abc. Probability. *9 units (3-0-6);* For course description, see Mathematics

CS/EE/IDS 143. Networks: Algorithms & Architecture. *12 units (3-4-5);* For course description, see Computer Science

CS/IDS 150 ab. Probability and Algorithms. *9 units (3-0-6);* For course description, see Computer Science

CS/IDS 153. Current Topics in Theoretical Computer Science. *9 units (3-0-6);* For course description, see Computer Science

ACM/IDS 154. Inverse Problems and Data Assimilation. *9 units (3-0-6);* For course description, see Applied & Computational Math

CMS/CS/CNS/EE/IDS 155. Machine Learning & Data Mining. *12 units (3-3-6);* For course description, see Computing and Mathematical Sciences

IDS/ACM/CS 157. Statistical Inference. *9 units (3-2-4); third term. Prerequisites: ACM/EE/IDS 116, Ma 3.* Statistical Inference is a branch of mathematical engineering that studies ways of extracting reliable information from limited data for learning, prediction, and decision making in the presence of uncertainty. This is an introductory course on statistical inference. The main goals are: develop statistical thinking and intuitive feel for the subject; introduce the most fundamental ideas, concepts, and methods of statistical inference; and explain how and why they work, and when they don't. Topics covered include summarizing

data, fundamentals of survey sampling, statistical functionals, jackknife, bootstrap, methods of moments and maximum likelihood, hypothesis testing, p-values, the Wald, Student's t-, permutation, and likelihood ratio tests, multiple testing, scatterplots, simple linear regression, ordinary least squares, interval estimation, prediction, graphical residual analysis. Instructor: Zuev.

IDS/ACM/CS 158. Fundamentals of Statistical Learning. *9 units (3-3-3); second term. Prerequisites: ACM/IDS 104, ACM/EE/IDS 116, IDS/ACM/CS 157.* The main goal of the course is to provide an introduction to the central concepts and core methods of statistical learning, an interdisciplinary field at the intersection of applied mathematics, statistical inference, and machine learning. The course focuses on the mathematics and statistics of methods developed for learning from data. Students will learn what methods for statistical learning exist, how and why they work (not just what tasks they solve and in what built-in functions they are implemented), and when they are expected to perform poorly. The course is oriented for upper level undergraduate students in IDS, ACM, and CS and graduate students from other disciplines who have sufficient background in linear algebra, probability, and statistics. The course is a natural continuation of IDS/ACM/CS 157 and it can be viewed as a statistical analog of CMS/CS/CNS/EE/IDS 155. Topics covered include elements of statistical decision theory, regression and classification problems, nearest-neighbor methods, curse of dimensionality, linear regression, model selection, cross-validation, subset selection, shrinkage methods, ridge regression, LASSO, logistic regression, linear and quadratic discriminant analysis, support-vector machines, tree-based methods, bagging, and random forests. Not offered 2025-26. Instructor: Zuev.

CS/CNS/EE/IDS 159. Advanced Topics in Machine Learning. *9 units (3-0-6);* For course description, see Computer Science

EE/CS/IDS 160. Fundamentals of Information Transmission and Storage. *9 units (3-0-6);* For course description, see Electrical Engineering

CS/IDS 162. Data, Algorithms and Society. *9 units (3-0-6);* For course description, see Computer Science

CS/CNS/EE/IDS 165. Foundations of Machine Learning and Statistical Inference. *12 units (3-3-6);* For course description, see Computer Science

CS/EE/IDS 166. Computational Cameras. *12 units (3-3-6);* For course description, see Computer Science

EE/CS/IDS 167. Introduction to Data Compression and Storage. *9 units (3-0-6);* For course description, see Electrical Engineering

ACM/EE/IDS 170. Mathematics of Signal Processing. *12 units (3-0-9);* For course description, see Applied & Computational Math

CS/IDS 172. Distributed Computing. *9 units (3-2-4);* For course description, see Computer Science

CS/IDS 178. Numerical Algorithms and their Implementation. *9 units (3-3-3);* For course description, see Computer Science

ACM/IDS 180 ab. Multiscale Modeling. *12 units (3-0-9);* For course description, see Applied & Computational Math

IDS 197. Undergraduate Reading in the Information and Data Sciences. *Units are assigned in accordance with work accomplished; first, second, third terms. Prerequisites: Consent of supervisor is required before registering.* Supervised reading in the information and data sciences by undergraduates. The topic must be approved by the reading supervisor and a formal final report must be presented on completion of the term. Graded pass/fail. Instructor: Staff.

IDS 198. Undergraduate Projects in Information and Data Sciences. *Units are assigned in accordance with work accomplished; first, second, third terms. Prerequisites: Consent of supervisor is required before registering.* Supervised research in the information and data sciences. The topic must be approved by the project supervisor and a formal report must be presented upon completion of the research. Graded pass/fail. Instructor: Staff.

IDS 199. Undergraduate thesis in the Information and Data Sciences. *9 units (1-0-8); first, second, third terms. Prerequisites: instructor's permission, which should be obtained sufficiently early to allow time for planning the research.* Individual research project, carried out under the supervision of a faculty member and approved by the option representative. Projects must include significant design effort and a written Report is required. Open only to upperclass students. Not offered on a pass/fail basis. Instructor: Staff.

ACM/IDS 204. Topics in Linear Algebra and Convexity. *9 units (3-0-6);* For course description, see Applied & Computational Math

ACM/IDS 213. Topics in Optimization. *9 units (3-0-6);* For course description, see Applied & Computational Math

ACM/IDS 216. Markov Chains, Discrete Stochastic Processes and Applications. *9 units (3-0-6);* For course description, see Applied & Computational Math

INFORMATION SCIENCE AND TECHNOLOGY

IST 4. Information and Logic. *9 units (3-0-6); third term.* The course explains the key concepts at the foundations of computing with physical substrates, including representations of numbers, Boolean algebra as an axiomatic system, Boolean functions and their representations, composition of functions and relations, implementing functions with circuits, circuit complexity, representation of computational processes with state diagrams, state diagrams as a composition of Boolean functions and memory, and the implementation of computational processes with finite state machines. The basic concepts covered in the course are connected to advanced topics like programming, computability, logic, complexity theory, information theory, and biochemical systems. Not offered on a pass/fail basis. Satisfies the menu requirement of the Caltech core curriculum. Not offered 2025-26. Instructor: Bruck.

INTEGRATED CORE

IC/Ph 1 abc. Integrated Core: Classical Mechanics and Electromagnetism. *9 units (3-1-5); first, second, and third terms. Prerequisites: concurrent enrollment in other integrated core classes and instructor permission.* An introduction to classical and modern physics. Topics included will be Newtonian physics, electromagnetism and light, special relativity, topics in statistical mechanics and thermodynamics. The material will be introduced from the perspective of their application to space travel and sustainable energy production. Instructors: Refael, George.

IC/Ch 1 abc. Integrated Core: General Chemistry with Lab. *6 units (3-1-2); 9 units (4-2-3); 6 units (1-3-2); first, second, and third terms. Prerequisites: concurrent enrollment in other integrated core classes and instructor permission.* An introduction to general chemistry focusing on the molecular level understanding of the structures, properties and reactivities of matter. The course introduces the physical and electronic structures of atoms and molecules, periodic properties, chemical bonding, atomic and molecular spectroscopy, equilibrium thermodynamics, acid-base chemistry, electrochemistry, kinetics, and fundamental reactions of organic and biochemistry. This material provides the foundation to develop the molecular basis of energy production, conversion, storage and transmission in both society and the biosphere, with carbon dioxide used as a reference system in the lectures and the lab to exemplify underlying chemical concepts. Satisfies the core requirements for Ch 1ab and Ch 3a/3x. Instructors: Rees, Blake.

IC/Ma 1 abc. Integrated Core: Linear Algebra and Multivariable Calculus. *6 units (3-0-3); 9 units (4-0-5); 3 units (2-0-1); first, second, and third terms. Prerequisites: concurrent enrollment in other integrated core*

classes and instructor permission. Linear algebra and multivariable calculus, including derivatives of vector functions, multiple integrals, line and surface integrals, theorems of Green and Stokes. Sequence of topics will be aligned with the applications of mathematics as they arise in the Integrated Core. Instructors: Graber, Gherman.

IC/Ge 1 abc. Integrated Core: Energy, Climate, and Carbon. *1 units (1-0-0); 2 units (1-1-0); 6 units (2-3-1); first, second, and third terms. Prerequisites: concurrent enrollment in other integrated core classes and instructor permission.* Introduction to energy in the Earth system, with emphasis on the Earth as an interacting set of dynamical systems, energy balance in the climate, the role of greenhouse gases, and strategies to capture and sequester carbon dioxide from the atmosphere. Includes a 3-day field trip before the start of new student orientation in the Fall. Instructor: Asimow.

IC/Bi 1 abc. Integrated Core: Energy in Biology. *2 units (1-1-0); 4 units (2-1-1); 3 units (1-1-1); first, second, and third terms. Prerequisites: concurrent enrollment in other integrated core classes and instructor permission.* A classroom- and laboratory-based introduction to fundamental principles in biology with a focus on bioenergetics. Topics include diverse modes of energy conservation, the relationship between catabolism and anabolism, free energy of the processes of life, and how microbial metabolic diversity has shaped the Earth and can be harnessed for energy and sustainability applications. Instructors: Newman, Bois.

IC 3. Integrated Core: Additional Introductory Laboratory. *3 units (0-2-1); third term. Prerequisites: concurrent enrollment in other integrated core classes and instructor permission.* This introductory lab will allow the student to investigate many of the concepts discussed in the Integrated Core lectures in a laboratory setting. The labs will cover topics such as kinematics, angular momentum, electric motor principles, and electromechanical power conversion. Students will also have the opportunity to become familiar with basic electronic circuits and test equipment such as power supplies, multimeters, and oscilloscopes. The student will be expected to do data analysis and comprehensive lab write-ups. Instructor: George.

IC/Hum 55 abc. Integrated Core: Introduction to Energy Humanities. *3 units (1-0-2); first, second, third terms. Prerequisites: concurrent enrollment in other integrated core classes and instructor permission.* This sequence of humanities courses will introduce students to political philosophy and ethics, historical research, and literary analysis, in conjunction with themes treated in other parts of the integrated core. Key topics will include the ethics of space travel, the history of Caltech energy research, and contemporary climate fiction. All three terms together count as the equivalent of a single 9-unit first-year humanities class; students may choose their other first-year humanities class from any area of humanities instruction. Instructor: Jahner.

LANGUAGES

L 102 abc. Elementary French. *9 units (3-0-6); first, second, third terms.* The course uses a multimedia program and emphasizes the acquisition of fundamental skills: oral ability, comprehension, writing, and reading. Students are evaluated based on quizzes and compositions (1/3), midterm and final (1/3), and class participation (1/3). The course is mainly designed for students with no previous knowledge of French. Students who have had French in secondary school or college must consult with the instructor before registering. Instructor: Orcel.

L 103 abc. Intermediate French. *9 units (3-0-6); first, second, third terms. Prerequisites: L 102 abc or equivalent.* The first two terms feature an extensive grammar review and group activities that promote self-expression. Op-Ed articles and a series of literary texts provide a basis for classroom discussion and vocabulary expansion. Several short-written compositions are required. The third term is designed to further develop an active command of the language. A variety of 19th- and 20th-century short stories are discussed in class to improve comprehension and oral proficiency. Students are expected to do an oral presentation, to write three short compositions, and a final paper. Instructors: Merrill, Orcel.

L 104. French Cinema. *9 units (3-0-6); first term. Prerequisites: L 103 abc or equivalent.* A critical survey of major directors, genres, and movements in French cinema. Particular attention is devoted to the development of film theory and criticism in France and their relation to film production. The course may also focus on problems of transposition from literature to cinema. The class includes screenings of films by Méliès, Dulac, Clair, Renoir, Carné, Pagnol, Cocteau, Bresson, Tati, Truffaut, Godard, Resnais, Lelouch, Malle, Pialat, Rohmer, and Varda. Students are expected to write three 5-page critical papers. Conducted in French. Not offered 2025-26.

L 105. Topics in French Literature. *9 units (3-0-6); second term. Prerequisites: L 103 abc or equivalent.* Offered concurrently with Hum 105. L 105 and L 116 are taught in alternate years. Topics may include the 20th-century major French novels; French modern theatre; conflicting memories of the second world war; coming of age novels; the French Muslim identity. Conducted in French. Students who write papers in English may enroll in this class as Hum 105, which satisfies the advanced humanities requirement. Instructor: Orcel.

L 106 abc. Elementary Japanese. *9 units (4-0-5); first, second, third terms. Prerequisites: L106a is required for L106b and L106b is required for L106c.* The goal of Elementary Japanese is to develop the ability to communicate in Japanese and to enable you to attain an elementary level of language proficiency in Japanese. You will have learned the Japanese writing systems, hiragana, katakana and kanji. Students who studied Japanese prior to this course must consult with the instructor

before registering. Instructor: Fujio.

L 107 abc. Intermediate Japanese. *9 units (3-0-6); first, second, third terms. Prerequisites: L 106 abc or equivalent.* Continued instruction and practice in conversation, building up vocabulary, and understanding complex sentence patterns. The emphasis, however, will be on developing reading skills. Recognition of approximately 1,000 characters. Instructor: Hirai.

L 108 abc. Advanced Japanese. *9 units (3-0-6); first, second terms. Prerequisites: L 107 abc or equivalent.* Developing overall language skills. Literary and newspaper readings. Technical and scientific translation. Improvement of listening and speaking ability so as to communicate with Japanese people in real situations. Recognition of the 1,850 general-use characters. Instructor: Hirai.

L/VC 109. Introduction to 20th-Century French Cinema. *9 units (3-0-6); first term.* This course introduces students to the artistic style and the social, historical, and political content of French films, starting with Méliès and the Lumière brothers and working through surrealism and impressionism, 1930s poetic realism, the Occupation, the New Wave, the Cinema du look, and some critically acclaimed auteurs of the end of the century. The class teaches students to look at film as a medium with its own techniques and formal principles. Conducted in English. Not offered 2025-26.

L 110 abc. Elementary Spanish. *9 units (3-0-6); first, second, third terms.* Grammar fundamentals and their use in understanding, speaking, reading, and writing Spanish. Exclusively for students with no previous knowledge of Spanish. Instructors: Arjona, Garcia.

L/VC 111. Introduction to 21st-Century French Cinema. *9 units (3-0-6); first term.* L/VC 109 and L/VC 111 are taught in alternate years. This course looks at popular genres (comedy, thriller, animation film) and auteur cinema. It focuses on major trends in contemporary French movies and their relationships to French society (exploration of class, ethnic, gender and sexual identity, etc.). It analyzes the reappropriation of the national heritage, the progressive feminization of the filmmaking profession and the new appearance of directors who are immigrants or children of immigrants. Throughout this class, students will further develop their understanding of the methods and concepts of cinema studies. Conducted in English. Instructor: Orcel.

L 112 abc. Intermediate Spanish. *9 units (3-0-6); first, second, third terms. Prerequisites: L 110 abc or equivalent.* Grammar review, vocabulary building, practice in conversation, and introduction to relevant history, literature, and culture. Literary reading and writing are emphasized in the second and third terms. Students who have studied Spanish elsewhere must consult with the instructor before registering. Instructor: Garcia.

L 114 abc. Spanish Language Literature and its Film Adaptations. *9 units (3-0-6); first, second, third terms. Prerequisites: L 112 abc or equivalent.* Offered concurrently with Hum 114abc. This course explores the mixed cultures of the Spanish speaking countries and the United States, through a compilation of novel excerpts, short stories, drama, music, poetry, and film. This heterogeneity of written and audiovisual texts aims to acquaint students with the rich cultures of the Spanish speaking peoples, from the standpoint of ethnicity, gender, and social class. The course also focuses on continuing to develop Spanish language skills. Conducted in Spanish. (a) The traditional role of women during dictatorships and their journey to freedom (b) Family relationships and their impact on mental and physical health (c) building gender, social, and economic equality. Each term can be taken independently. Students who write papers in English may enroll in this class as humanities, which satisfies the advanced humanities requirement. Instructor: Arjona.

L 115 abc. Hispanic Cultures in Film and Literature. *9 units (3-0-6); first, second, third terms. Prerequisites: L 112 abc or equivalent.* Offered concurrently with Hum 115. This course introduces students to narrative film and literature from the Hispanic world, with an emphasis on the hero figure. It also takes up hybridization and transculturation in the Americas, specifically in Mexico, Peru, and Cuba, as well as film and narratives of Spain from the Civil War to the present. Conducted in Spanish. (a) Basics of Hispanic films and narratives, and their socio-cultural roots (b) Hybridization and mestizo cultures in the Hispanic world (c) The last century in Hispanic film and narrative. Each term can be taken independently. Students who write papers in English may enroll in this class as Hum 115, which satisfies the advanced humanities requirement. Not offered 2025-26.

L 116. Topics in French Culture. *9 units (3-0-6); second term. Prerequisites: L 103 abc or equivalent.* Offered concurrently with Hum 116. L 105 and L 116 given in alternate years. The course focuses on contemporary France. Topics may include France and the European Union; political parties and elections; family life; social protection; religion; education; media and technology. Conducted in French. Students who write papers in English may enroll in this class as Hum 116, which satisfies the advanced humanities requirement. Not offered 2025-26.

L 130 abc. Elementary German. *9 units (3-0-6); first, second, third terms.* Grammar fundamentals and their use in aural comprehension, speaking, reading, and writing. Students who have had German in secondary school or college must consult with the instructor before registering. Instructor: Aebi.

L 132 abc. Intermediate German. *9 units (3-0-6); first, second, third terms. Prerequisites: L 130 abc or equivalent.* Reading of short stories and plays, grammar review, aural and oral drills and exercises, expansion of vocabulary, and practice in reading, writing, and

conversational skills. Second and third terms will emphasize written expression, technical/ scientific translation, and literary readings. Students who have studied German elsewhere must consult with the instructor before registering. Instructor: Aebi.

L 139. Translation Theory and Practice (Chinese Historical Sources Seminar). *9 units (3-0-6); first term.* This seminar will introduce students to the problems and practices of historical translation for academic purposes, with a focus on primary materials from Chinese history. Students will take responsibility for an individual translation project, participate in seminar discussions and collaborative projects to improve the translations being made, and discuss the philosophical and methodological questions at the heart of the practice of translation. Advanced proficiency in written Chinese is required. Students who write analyses (4,000 words) of the sources being translated may enroll in this class as H 139, which satisfies the advanced humanities credit. Not offered 2025-26.

H/L 142. Perspectives on History through Russian Literature. *9 units (3-0-6);* For course description, see History

L/Hum 150. Japanese Literature in Translation. *9 units (3-0-6); third term.* Read and examine the selected classical Japanese literature and its traditions from 7th to 11th century from the perspectives of women, anti-heroes, and religions. A comparative analysis is applied to many genres such as oral traditions, performing arts, films, picture scrolls, comics, and anime to understand how Japanese think, and how Shinto and Buddhism have formed their ways of life, ethics, and concepts of life and death. Read selected portions of "The Kojiki", "Manyoshu", "The Tale of Ise", "The tale of the Bamboo-Cutter" (The Tale of the Moon Princess), and "The Tale of Genji.". Instructor: Hirai.

L/Hum 151. Japanese Literature in Translation from Medieval to Pre-modern Japan. *9 units (3-0-6); third term.* Read and examine the selected Medieval to pre-modern Japanese literature and its traditions from 11th to 18th century from the perspectives of women, anti-heroes, and religions. A comparative analysis is applied to many genres such as oral traditions, performing arts, films, picture scrolls, comics, and anime to understand how Japanese think, and how Shinto, Buddhism, Neo-Confucianism, as well as the social systems, have formed their ways of life, ethics, and concepts of life and death. Read "The Princess Who Loved Insects" from "The Tsutsumi-Chunagon Monogatari", selected chapters of "The Tale of The Heike", "The Konjyaku Monogatari", and "Otogizoshi". Also read "The Double Suicide at Sonezaki" and "The Double Suicide at Amijima." Not offered 2025-26.

L/Hum 152. Classical French Literature in Translation. *9 units (3-0-6); third term.* This course introduces students to French theater and fiction of the seventeenth and eighteenth centuries, from Molière's comedies (The Misanthrope, Tartuffe), and Racine's tragedy Phaedra to the novels of Madame de Lafayette, Marivaux, and Laclos. Topics include the

aesthetics of neoclassical theater, the rise of the novel, historical and social contexts (the reign of Louis XIV, libertinage, Rousseauism), and writers' creative development. Covers the period 1643-1789. Conducted in English, but students may read the French originals. Instructor: Merrill.

L/VC 153. Refugees and Migrants' Visual and Textual Representations. *9 units (3-0-6); second term.* This course focuses on the refugees and migrants' images in documentaries, narrative films, graphic novels, fictional texts, poetic works, and autobiographical narratives. It investigates how these representations participate in the development and strengthening of political discourse. Works by authors such as Hannah Arendt, Antje Ellermann, Achille Mbembe, Martin A. Schain, and Sasha Polakow-Suransky will provide some context to our analysis. Topics discussed in class include the historical and economic relationships of Europe with the refugees and migrants' countries of origin, the rise of anti-immigrant politics and its significance for the future of the European Union, but also its impact on social peace, in France in particular. This course is taught in English and satisfies the advanced humanities requirement. Not offered 2025-26.

L/Hum 154. The Modern French Novel in Translation. *9 units (3-0-6); third term.* This course introduces students to the French novel of the nineteenth and twentieth centuries, from the realist masterpieces of Stendhal (The Red and the Black), Balzac (Old Goriot), and Flaubert (Madame Bovary/Sentimental Education) to Marcel Proust's In Search of Lost Time. Topics include the literary representation of reality, historical and social contexts (the Bourbon Restoration, 1848 Revolution, the Third Republic), and the decline of the French nobility. Covers 1814-1918. Conducted in English, but students may read the French originals. Not offered 2025-26.

L/Hum 162. Spanish and Latin American Literature in Translation. *9 units (3-0-6); third term.* This class is an introduction to the literary masterworks of the Hispanic tradition from the 16th to the 20th centuries. Readings and discussions are in English, but students may read Spanish originals. Not offered 2025-26.

L 169. Chinese Cinema. *9 units (3-0-6); third term.* Offered concurrently with Hum 169. This course offers an overview of Chinese-language films from the early twentieth century to the present. We will view a selection of cinematic masterpieces and place each film in its historical context, considering both the aesthetic form and socio-cultural content of the film. Lecture topics include the Golden Ages of early Chinese cinema, Hong Kong New Wave, the Fifth Generation of Chinese filmmakers, Taiwan New Cinema, the Sixth Generation of Chinese filmmakers, Chinese animation, Asia-Pacific co-productions, and sci-fi movies. Students who write papers in English may enroll in this class as Hum 169, which satisfies the advanced humanities requirement. This course can be repeated for credit when the course content changes. Not offered 2025-26. .

L 170 abc. Introduction to Chinese. *9 units (3-0-6); first, second, third terms.* An introductory course in standard Chinese (Mandarin) designed for students with no previous knowledge of the language. The course introduces the fundamentals of Chinese, including pronunciation, grammar, and Chinese characters, emphasizing the four basic language skills: listening, speaking, reading, and writing. By the end of the three-term sequence, students will have acquired knowledge of basic rules of grammar and the ability to converse, read, and write on simple topics of daily life, and will have command of more than 800 Chinese compounds and 700 characters. Instructor: Wang.

L 171 abc. Accelerated Chinese for Heritage Learners. *9 units (3-0-6); first, second terms. Prerequisites: Prior exposure to the language.* A streamlined course designed for students who have acquired some speaking, writing, or reading skills, either from home or school. The course aims at consolidating and developing the students' ability in listening, conversation, reading, and writing. By the end of the three-term sequence, students should have command of 2000 Chinese compounds and 1500 characters, and be able to live or work in a Chinese speaking environment. Students who completed L 171 abc can advance to L 173 ab (Advanced Chinese). Instructor: Zhu.

L 172 abc. Intermediate Chinese. *9 units (3-0-6); first, second, third terms. Prerequisites: L 170 abc or L 171 abc or equivalent.* A course designed to meet the personal interests and future professional goals of students who have had one year of elementary modern Chinese. Students will learn new vocabulary, sentence patterns, idiomatic expressions, and proverbs, as well as insights into Chinese society, culture, and customs. Instructor: Zhu.

L 173. Advanced Chinese - Contemporary China. *9 units (3-0-6); first, second terms. Prerequisites: L 171 abc, L 172 abc or equivalent.* A course designed as a bridge between language and content courses. It provides the opportunity to further develop overall language proficiency through reading essays on Chinese culture, stories, and news editorials. Multimedia is included. By the end of this course, students should have acquired the basic skills to read and research about Chinese culture and society. Classes are conducted primarily in Chinese. Instructor: Wang.

L 174. Topics in Masterpieces of Chinese Writing. *9 units (3-0-6); third term. Prerequisites: instructor's permission.* Offered concurrently with Hum 174. Reading and discussion of representative Chinese written work throughout Chinese history, including philosophical texts and literary works in different genres. Students are expected to examine these works in light of their sociopolitical and historical contexts. Students who write papers in English may enroll in this class as Hum 174, which satisfies the advanced humanities requirement. This course can be repeated for credit when the course content changes. Not offered 2025-26.

L 175. French Conversation. *6 units (3-0-3); third term. Prerequisites: L 102 abc and L 103 abc or equivalent.* Intense training in oral expression, pronunciation, vocabulary, listening comprehension and fluency. This course is designed for students interested in scientific French, planning to attend Ecole Polytechnique, or enrolled in the NSF REU program. Caltech professors and postdocs intending to spend time in France are also welcome. Discussion materials and guest lectures will focus on technical language to prepare students for their classes in math and science. Taught in French. L 175 can be repeated for credit as content changes every year. Not offered 2025-26.

L 176. Chinese Conversation. *9 units (3-0-6); third term. Prerequisites: L 170 abc or L 171 abc or equivalent.* Training in oral expression, pronunciation, vocabulary, listening comprehension and fluency. The class is designed for students who have learned one year of Chinese and plan to incorporate it into their future professional or social lives. News, guest talks and discussion forums will be included. Can be repeated for credit as content changes every year. Instructor: Zhu.

L 177. Advanced Chinese - Classical Chinese. *9 units (3-0-6); third term. Prerequisites: L 171abc, L 172abc or equivalent.* This course provides students with solid grasp of the basic patterns and vocabulary of classical Chinese through classical fables, and gradually introduce students to more complex and lengthy readings including philosophical and historical works, prose, and poetry. The class will also focus on the differences and similarities of word choices and expressions in modern and classical Chinese, in order to facilitate students' understanding of modern Chinese literary styles. Instructor: Wang.

H/L 191. Perspectives on History through German Literature. *9 units (3-0-6);* For course description, see History

LAW

Pl/Law 99. Causation and Responsibility. *9 units (3-0-6);* For course description, see Philosophy

MATERIALS SCIENCE

MS 78 abc. Senior thesis. *9 units; first, second, third terms. Prerequisites: instructor's permission.* Supervised research experience, open only to senior materials science majors. Starting with an open-ended topic, students will plan and execute a project in materials science and engineering that includes written and oral reports based upon actual results, synthesizing topics from their course work. Only the first term may be taken pass/fail. Instructor: Staff.

MS 90. Materials Science Laboratory. *9 units (1-6-2); third term. Prerequisites: MS 115 recommended.* An introductory laboratory in relationships between the structure and properties of materials. Experiments involve materials processing and characterization by X-ray diffraction, scanning electron microscopy, and optical microscopy. Students will learn techniques for measuring mechanical and electrical properties of materials, as well as how to optimize these properties through microstructural and chemical control. Independent projects may be performed depending on the student's interests and abilities. Instructor: Staff.

MS 100. Advanced Work in Materials Science. *;* The staff in materials science will arrange special courses or problems to meet the needs of students working toward the M.S. degree or of qualified undergraduate students. Graded pass/fail for research and reading. Instructor: Staff.

APh/MS/ME 105 abc. States of Matter. *9 units (3-0-6);* For course description, see Applied Physics

MS 110 abc. Materials Research Lectures. *1 unit (1-0-0); first, second, third terms.* A seminar course designed to introduce advanced undergraduates and graduate students to modern research in materials science. Instructors: Faber, Falson, Fultz.

ChE/ESE/ME/MS 111. Sustainable Engineering. *9 units (3-0-6);* For course description, see Chemical Engineering

ChE/Ch/MS 113. Squishy Engineering: Using Soft Materials to Solve Hard Problems. *9 units (3-0-6);* For course description, see Chemical Engineering

MS 115. Fundamentals of Materials Science. *9 units (3-0-6); first term. Prerequisites: Ph 2.* An introduction to the structure and properties of materials and the processing routes utilized to optimize properties. All major classes of materials are covered, including metals, ceramics, electronic materials, composites, and polymers. The relationships between chemical bonding, crystal structure, defects, thermodynamics, phase equilibria, microstructure, and properties are described. Instructor: Staff.

MS/ME/MedE 116. Mechanical Behavior of Materials. *9 units (3-0-6); second term.* Introduction to the mechanical behavior of solids, emphasizing the relationships between microstructure, architecture, defects, and mechanical properties. Elastic, inelastic, and plastic properties of crystalline and amorphous materials. Relations between stress and strains for different types of materials. Introduction to dislocation theory, motion and forces on dislocations, strengthening mechanisms in crystalline solids. Nanomaterials: properties, fabrication, and mechanics. Architected solids: fabrication, deformation, failure, and energy absorption. Biomaterials: mechanical properties of composites, multi-scale microstructure, biological vs. synthetic, shear lag model.

Fracture in brittle solids and linear elastic fracture mechanics. Instructor: Greer.

MS 121. Laboratory Research Methods in Materials Science. *9 units (1-4-4); second term. Prerequisites: MS 115 or graduate standing.* Introduction to experimental methods and approaches for the analysis of structure, dynamics, and properties of materials. Staff members with expertise in various areas including mechanical testing, calorimetry, X-ray diffraction, scanning and transmission electron microscopy, solid state NMR and electrochemistry will introduce and supervise experiments in their specialty. As the situation permits, students are given a choice in selecting experiments. Not offered 2025-26.

MS/APh 122. Diffraction, Imaging, and Structure. *9 units (0-4-5); second term. Prerequisites: MS 132, may be taken concurrently.* Experimental methods in transmission electron microscopy of inorganic materials including diffraction, spectroscopy, conventional imaging, high resolution imaging and sample preparation. Weekly laboratory exercises to complement material in MS 132. Not offered 2025-26. Instructor: Staff.

MS 125. Advanced Transmission Electron Microscopy. *9 units (1-6-2); third term. Prerequisites: MS 122.* Diffraction contrast analysis of crystalline defects. Phase contrast imaging. Physical optics approach to dynamical electron diffraction and imaging. Microbeam methods for diffraction and imaging. Chemical analysis by energy dispersive X-ray spectrometry and electron energy loss spectrometry. Not offered 2025-26.

MS 131. Structure and Bonding in Materials. *9 units (3-0-6); first term. Prerequisites: graduate standing or introductory quantum mechanics.* Electronic states in atoms and molecules. Born-Oppenheimer approximation. Crystal structure, including databases and visualization. Reciprocal space and Brillouin zone. Band theory using tight binding and plane waves. Introduction to density functional theory. Bonding and electronic structure in metals, semiconductors, ionic crystals, and complex oxides. Symmetry in materials: point groups, space groups, and time-reversal symmetry. Physical properties of crystals and their tensor representation. Introduction to correlated and topological quantum materials. Instructor: Bernardi.

MS 132. Diffraction and Structure. *9 units (3-0-6); second term. Prerequisites: graduate standing or instructor's permission.* Principles of electron, X-ray, and neutron diffraction with applications to materials characterization. Imaging with electrons, and diffraction contrast of crystal defects. Kinematical theory of diffraction: effects of strain, size, disorder, and temperature. Correlation functions in solids, with introduction to space-time correlation functions. Instructor: Fultz.

MS 133. Kinetic Processes in Materials. *9 units (3-0-6); third term. Prerequisites: APh 105 b or ChE/Ch 164, or instructor's permission.*

Kinetic master equation, uncorrelated and correlated random walk, diffusion. Mechanisms of diffusion and atom transport in solids, liquids, and gases. Coarsening of microstructures. Nonequilibrium processing of materials. Instructors: Greer, Kornfield.

APh/MS 141. Introduction to Computational Methods for Science and Engineering. *9 units (3-0-6);* For course description, see Applied Physics

MS 142. Application of Diffraction Techniques in Materials Science. *9 units (2-3-4); second term. Prerequisites: Instructor's permission.* Applications of X-ray and neutron diffraction methods to the structural characterization of materials. Emphasis is on the analysis of polycrystalline materials but some discussion of single crystal methods is also presented. Techniques include quantitative phase analysis, crystalline size measurement, lattice parameter refinement, internal stress measurement, quantification of preferred orientation (texture) in materials, Rietveld refinement, and determination of structural features from small angle scattering. Homework assignments will focus on analysis of diffraction data. Samples of interest to students for their thesis research may be examined where appropriate. Not offered 2025-26.

MS 150 abc. Topics in Materials Science. *Units to be arranged; first, second, third terms.* Content will vary from year to year, but will be at a level suitable for advanced undergraduate or graduate students. Topics are chosen according to the interests of students and faculty. Visiting faculty may present portions of the course. Instructor: Staff.

APh/Ph/MS 152. Fundamentals of Fluid Flow in Small Scale Systems. *9 units (3-0-6);* For course description, see Applied Physics

APh/Ph/Ae/MS 153. Fundamentals of Energy and Mass Transport in Small Scale Systems. *9 units (3-0-6);* For course description, see Applied Physics

MS/ME 161. Imperfections in Crystals. *9 units (3-0-6); third term. Prerequisites: graduate standing or MS 115.* The relation of lattice defects to the physical and mechanical properties of crystalline solids. Introduction to point imperfections and their relationships to transport properties in metallic, covalent, and ionic crystals. Kroeger-Vink notation. Introduction to dislocations: geometric, crystallographic, elastic, and energetic properties of dislocations. Dislocation reactions and interactions including formation of locks, stacking faults, and surface effects. Relations between collective dislocation behavior and mechanical properties of crystals. Introduction to computer simulations of dislocations. Grain boundaries. The structure and properties of interfaces in solids. Emphasis on materials science aspects of role of defects in electrical, morphological, optical, and mechanical properties of solids. Not offered 2025-26. Instructor: Greer.

MS/APh 162. Electronic Structure of Materials. *9 units (3-0-6); second term. Prerequisites: APh 114a (or equivalent solid-state physics), or MS131 strongly recommended.* A course examining the structure-symmetry related properties of crystalline matter. The course will develop an in-depth understanding of electronic dispersions based on the atomic constituents of the structure and explore how matter couples to external stimuli such as light, magnetic fields, pressure, and strain, based on the underlying symmetry of the lattice. Modern materials, such as oxides and two-dimensional materials, will be used to illustrate how these properties are explored in a research setting. Instructor: Falson.

MS/ME 166. Fracture of Brittle Solids. *9 units (3-0-6); third term. Prerequisites: graduate standing or MS 115 and MS 116.* The mechanical response of brittle materials (ceramics, glasses and some network polymers) will be treated using classical elasticity, energy criteria, and fracture mechanics. The influence of environment and microstructure on mechanical behavior will be explored. Transformation toughened systems, large-grain crack-bridging systems, nanostructured ceramics, porous ceramics, anomalous glasses, and the role of residual stresses will be highlighted. Strength, flaw statistics and reliability will be discussed. Instructor: Faber.

MS/APh 171. Inelastic Scattering of Materials, Molecules, and Condensed Matter. *9 units (3-0-6); third term. Prerequisites: EE/APh 131 or MS 132 or equivalent.* Review of Patterson function and memory function for space or time correlations. Van Hove function for correlated dynamics in space and time. Dynamical structure factors of solids and liquids. Measurements of energy and momentum of dispersive excitations in crystals using neutrons, x-rays, and electrons. Topics in inelastic scattering of high-energy electrons and x-rays, such as core spectroscopy with high-energy electrons, resonant and non-resonant x-ray spectroscopies. Free electron laser methodology and ultrafast pump-probe measurements. The final project will be a proposal for an experiment. Instructor: Fultz.

MS 200. Advanced Work in Materials Science. *;* The staff in materials science will arrange special courses or problems to meet the needs of advanced graduate students.

Ae/AM/MS/ME 213. Mechanics and Materials Aspects of Fracture. *9 units (3-0-6);* For course description, see Aerospace

ME/MS/AM 221. Effective properties of heterogenous and meta-materials. *9 units (3-0-6);* For course description, see Mechanical Engineering

ME/MS/Ae/AM 224. Multifunctional Materials. *9 units (3-0-6);* For course description, see Mechanical Engineering

APh/MS 256. Computational Solid State Physics and Materials Science. *9 units (3-3-3);* For course description, see Applied Physics

MS 300. Thesis Research. *;*

MATHEMATICS

IC/Ma 1 abc. Integrated Core: Linear Algebra and Multivariable Calculus. *6 units (3-0-3); 9 units (4-0-5); 3 units (2-0-1);* For course description, see Integrated Core

Ma 1 abc. Calculus of One and Several Variables and Linear Algebra. *9 units (4-0-5); first, second, third terms. Prerequisites: high-school algebra, trigonometry, and calculus.* Special section of Ma 1 a, 12 units (5-0-7). Review of calculus. Complex numbers, Taylor polynomials, infinite series. Comprehensive presentation of linear algebra. Derivatives of vector functions, multiple integrals, line and path integrals, theorems of Green and Stokes. Ma 1 b, c is divided into two tracks: analytic and practical. Students will be given information helping them to choose a track at the end of the fall term. There will be a special section or sections of Ma 1 a for those students who, because of their background, require more calculus than is provided in the regular Ma 1 a sequence. These students will not learn series in Ma 1 a and will be required to take Ma 1 d. Instructors: Conlon, Gherman, Flach, T. Yu.

Ma 1 d. Series. *3 units (2-0-1); second term. Prerequisites: special section of Ma 1 a.* This is a course intended for those students in the special calculus-intensive sections of Ma 1 a who did not have complex numbers, Taylor polynomials, and infinite series during Ma 1 a. It may not be taken by students who have passed the regular Ma 1 a. Instructor: Gherman.

Ma 2/102. Differential Equations. *9 units (4-0-5); first term. Prerequisites: Ma 1 abc.* The course is aimed at providing an introduction to the theory of ordinary differential equations, with a particular emphasis on equations with well known applications ranging from physics to population dynamics. The material covered includes some existence and uniqueness results, first order linear equations and systems, exact equations, linear equations with constant coefficients, series solutions, regular singular equations, Laplace transform, and methods for the study of nonlinear equations (equilibria, stability, predator-prey equations, periodic solutions and limiting cycles). Instructors: Babecki, Hutchcroft.

Ma 3/103. Introduction to Probability and Statistics. *9 units (4-0-5); second term. Prerequisites: Ma 1 abc.* This course is an introduction to the main ideas of probability and statistics. The first half is devoted to the fundamental concepts of probability theory, including basic combinatorics, random variables, independence, conditional probability, and the central limit theorem. The second half is devoted to statistical

reasoning, including methods for the collection, organization, analysis, and interpretation of data. Topics covered will include parameter estimation, hypothesis testing, confidence intervals, Bayesian inference, and linear regression. The course will emphasize the application of statistics to engineering and the sciences. Instructor: Pachter and Halgrimmsdottir.

Ma 4/104. Introduction to Mathematical Chaos. *9 units (3-0-6); third term.* An introduction to the mathematics of "chaos." Period doubling universality, and related topics; interval maps, symbolic itineraries, stable/unstable manifold theorem, strange attractors, iteration of complex analytic maps, applications to multidimensional dynamics systems and real-world problems. Possibly some additional topics, such as Sarkovski's theorem, absolutely continuous invariant measures, sensitivity to initial conditions, and the horseshoe map. Instructor: Marcolli.

Ma 5/105 abc. Introduction to Abstract Algebra. *9 units (3-0-6); first, second, third terms.* Introduction to groups, rings, fields, and modules. The first term is devoted to groups and includes treatments of semidirect products and Sylow's theorem. The second term discusses rings and modules and includes a proof that principal ideal domains have unique factorization and the classification of finitely generated modules over principal ideal domains. The third term covers field theory, Galois theory, and an introduction to character theory for finite groups. Instructors: Mantovan, Aluffi, Conlon.

Ma/CS 6/106 abc. Introduction to Discrete Mathematics. *9 units (3-0-6); first, second, third terms. Prerequisites: for Ma/CS 6 c, Ma/CS 6 a or Ma 5 a or instructor's permission.* First term: a survey emphasizing graph theory, algorithms, and applications of algebraic structures. Graphs: paths, trees, circuits, breadth-first and depth-first searches, colorings, matchings. Enumeration techniques; formal power series; combinatorial interpretations. Topics from coding and cryptography, including Hamming codes and RSA. Second term: directed graphs; networks; combinatorial optimization; linear programming. Permutation groups; counting nonisomorphic structures. Topics from extremal graph and set theory, and partially ordered sets. Third term: syntax and semantics of propositional and first-order logic. Introduction to the Godel completeness and incompleteness theorems. Elements of computability theory and computational complexity. Discussion of the P=NP problem. Instructors: T. Yu, Babecki, Marcolli.

Ma 7/107. Number Theory for Beginners. *9 units (3-0-6); third term.* Some of the fundamental ideas, techniques, and open problems of basic number theory will be introduced. Examples will be stressed. Topics include Euclidean algorithm, primes, Diophantine equations, including an + bn = cn and a2-db2 = Â±1, constructible numbers, composition of binary quadratic forms, and congruences. Instructor: Fu.

Ma 8. Problem Solving in Calculus. *3 units (3-0-0); first term. Prerequisites: simultaneous registration in Ma 1 a.* A three-hour per week hands-on class for those students in Ma 1 needing extra practice in problem solving in calculus. Instructor: Graber.

Ma 10. Oral Presentation. *3 units (2-0-1); first term.* Open for credit to anyone. First-year students must have instructor's permission to enroll. In this course, students will receive training and practice in presenting mathematical material before an audience. In particular, students will present material of their own choosing to other members of the class. There may also be elementary lectures from members of the mathematics faculty on topics of their own research interest. Instructor: Song.

Ma 11. Mathematical Writing. *3 units (0-0-3); third term. Prerequisites: First-year students must have instructor's permission to enroll.* Students will work with the instructor and a mentor to write and revise a self-contained paper dealing with a topic in mathematics. In the first week, an introduction to some matters of style and format will be given in a classroom setting. Some help with typesetting in TeX may be available. Students are encouraged to take advantage of the Hixon Writing Center's facilities. The mentor and the topic are to be selected in consultation with the instructor. It is expected that in most cases the paper will be in the style of a textbook or journal article, at the level of the student's peers (mathematics students at Caltech). Fulfills the Institute scientific writing requirement. Not offered on a pass/fail basis. Instructor: Conlon.

FS/Ma 12. First-Year Seminar: The Mathematics of Enzyme Kinetics. *6 units (2-0-4);* For course description, see First-Year Seminars

Ma 13. Problem Solving in Vector Calculus. *2 units (2-0-0); second term. Prerequisites: Concurrent registration in Ph 1 b.* A two-hour per week, hands-on class for those students enrolled in Ph 1 b needing extra practice with problem solving in vector calculus. Not offered 2025-26.

Ma 14. Student-Taught Topics in Mathematics. *3 units (3-0-0); first, second, third terms. Prerequisites: Ma 1 abc or instructor's permission.* Each section of Ma 14 covers a topic in mathematics with associated sets or projects. Sections are designed and taught by an undergraduate student (or students) under the supervision of a MA faculty member. Ma 14 may be repeated for credit of up to a total of nine units. Graded pass/fail. Instructor: Staff.

Ma 17. How to Solve It. *4 units (2-0-2); first term.* There are many problems in elementary mathematics that require ingenuity for their solution. This is a seminar-type course on problem solving in areas of mathematics where little theoretical knowledge is required. Students will work on problems taken from diverse areas of mathematics; there is no prerequisite and the course is open to first-year. May be repeated for credit. Graded pass/fail. Instructor: Zhang.

Ma 20. Frontiers in Mathematics. *1 unit (1-0-0); first term. Prerequisites: Open for credit to first-year students and sophomores.* Weekly seminar by a member of the math department or a visitor, to discuss their research at an introductory level. The course aims to introduce students to research areas in mathematics and help them gain an understanding of the scope of the field. Graded pass/fail. Instructor: Song.

Ma 92 abc. Senior Thesis. *9 units (0-0-9); first, second, third terms. Prerequisites: To register, the student must obtain permission of the mathematics undergraduate representative.* Open only to senior mathematics majors who are qualified to pursue independent reading and research. This research must be supervised by a faculty member. The research must begin in the first term of the senior year and will normally follow up on an earlier SURF or independent reading project. Two short presentations to a thesis committee are required: the first at the end of the first term and the second at the midterm week of the third term. A draft of the written thesis must be completed and distributed to the committee one week before the second presentation. Graded pass/fail in the first and second terms; a letter grade will be given in the third term.

Ma 97. Research in Mathematics. *Units to be arranged in accordance with work accomplished;* This course is designed to allow students to continue or expand summer research projects and to work on new projects. Students registering for more than 6 units of Ma 97 must submit a brief (no more than 3 pages) written report outlining the work completed to the undergraduate option rep at the end of the term. Approval from the research supervisor and student's adviser must be granted prior to registration. Graded pass/fail.

Ma 98. Independent Reading. *3-6 units by arrangement;* Occasionally a reading course will be offered after student consultation with a potential supervisor. Topics, hours, and units by arrangement. Graded pass/fail.

Ma 108 abc. Classical Analysis. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 1 or equivalent, or instructor's permission. May be taken concurrently with Ma 109.* First term: structure of the real numbers, topology of metric spaces, a rigorous approach to differentiation in R^n. Second term: brief introduction to ordinary differential equations; Lebesgue integration and an introduction to Fourier analysis. Third term: the theory of functions of one complex variable. Instructors: Reeves, Looi, Caniato.

Ma 109 abc. Introduction to Geometry and Topology. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 2 or equivalent. We recommend Ma 5 a and Ma 108 a be taken previously or concurrently.* First term: aspects of point set topology, and an introduction to geometric and algebraic methods in topology. Second term: the differential geometry of curves and surfaces in two- and three-dimensional Euclidean space. Third term: an introduction to

differentiable manifolds. Transversality, differential forms, and further related topics. Instructors: Ryoo, Caniato.

Ma 110 abc. Analysis. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 108 or previous exposure to metric space topology, Lebesgue measure.* First term: integration theory and basic real analysis: topological spaces, Hilbert space basics, Fejer's theorem, measure theory, measures as functionals, product measures, L^p -spaces, Baire category, Hahn- Banach theorem, Alaoglu's theorem, Krein-Millman theorem, countably normed spaces, tempered distributions and the Fourier transform. Second term: basic complex analysis: analytic functions, conformal maps and fractional linear transformations, idea of Riemann surfaces, elementary and some special functions, infinite sums and products, entire and meromorphic functions, elliptic functions. Third term: harmonic analysis; operator theory. Harmonic analysis: maximal functions and the Hardy-Littlewood maximal theorem, the maximal and Birkoff ergodic theorems, harmonic and subharmonic functions, theory of H^p -spaces and boundary values of analytic functions. Operator theory: compact operators, trace and determinant on a Hilbert space, orthogonal polynomials, the spectral theorem for bounded operators. If time allows, the theory of commutative Banach algebras. Instructors: Heinävaara, Makarov, Isett.

Ma 111 abc. Topics in Analysis. *9 units (3-0-6); third term. Prerequisites: Ma 110 or instructor's permission.* This course will discuss advanced topics in analysis, which vary from year to year. Topics from previous years include potential theory, bounded analytic functions in the unit disk, probabilistic and combinatorial methods in analysis, operator theory, C*-algebras, functional analysis. The third term will cover special functions: gamma functions, hypergeometric functions, beta/Selberg integrals and q-analogues. Time permitting: orthogonal polynomials, Painleve transcendents and/or elliptic analogues. Not offered 2025-26.

Ma 112 ab. Statistics. *9 units (3-0-6); second term. Prerequisites: Ma 2 a probability and statistics or equivalent.* The first term covers general methods of testing hypotheses and constructing confidence sets, including regression analysis, analysis of variance, and nonparametric methods. The second term covers permutation methods and the bootstrap, point estimation, Bayes methods, and multistage sampling. Not offered 2025-26.

Ma 116 abc. Mathematical Logic and Axiomatic Set Theory. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 5 or equivalent, or instructor's permission.* First term: Introduction to first-order logic and model theory. The Godel Completeness Theorem. Definability, elementary equivalence, complete theories, categoricity. The Skolem-Lowenheim Theorems. The back and forth method and Ehrenfeucht-Fraisse games. Fraisse theory. Elimination of quantifiers, applications to algebra and further related topics if time permits. Second and third terms: Axiomatic set theory, ordinals and cardinals, the Axiom of Choice and the Continuum Hypothesis. Models of set theory,

independence and consistency results. Topics in descriptive set theory, combinatorial set theory and large cardinals. Not offered 2025-26.

Ma/CS 117 abc. Computability Theory. *9 units (3-0-6); first, second terms. Prerequisites: Ma 5 or equivalent, or instructor's permission.* Various approaches to computability theory, e.g., Turing machines, recursive functions, Markov algorithms; proof of their equivalence. Church's thesis. Theory of computable functions and effectively enumerable sets. Decision problems. Undecidable problems: word problems for groups, solvability of Diophantine equations (Hilbert's 10th problem). Relations with mathematical logic and the Gödel incompleteness theorems. Decidable problems, from number theory, algebra, combinatorics, and logic. Complexity of decision procedures. Inherently complex problems of exponential and superexponential difficulty. Feasible (polynomial time) computations. Polynomial deterministic vs. nondeterministic algorithms, NP-complete problems and the P = NP question. Not offered 2025-26.

Ma 118. Topics in Mathematical Logic: Geometrical Paradoxes. *9 units (3-0-6); second term. Prerequisites: Ma 5 or equivalent, or instructor's permission.* This course will provide an introduction to the striking paradoxes that challenge our geometrical intuition. Topics to be discussed include geometrical transformations, especially rigid motions; free groups; amenable groups; group actions; equidecomposability and invariant measures; Tarski's theorem; the role of the axiom of choice; old and new paradoxes, including the Banach-Tarski paradox, the Laczkovich paradox (solving the Tarski circle-squaring problem), and the Dougherty-Foreman paradox (the solution of the Marczewski problem). Not offered 2025-26.

Ma 120 abc. Abstract Algebra. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 5 or equivalent or instructor's permission.* This course will discuss advanced topics in algebra. Among them: an introduction to commutative algebra and homological algebra, infinite Galois theory, Kummer theory, Brauer groups, semisimiple algebras, Weddburn theorems, Jacobson radicals, representation theory of finite groups. Instructors: Svoboda, Sugimoto.

Ma 121 ab. Combinatorial Analysis. *9 units (3-0-6); first, second terms. Prerequisites: Ma 5.* A survey of modern combinatorial mathematics, starting with an introduction to graph theory and extremal problems. Flows in networks with combinatorial applications. Counting, recursion, and generating functions. Theory of partitions. (0, 1)-matrices. Partially ordered sets. Latin squares, finite geometries, combinatorial designs, and codes. Algebraic graph theory, graph embedding, and coloring. Instructors: Dong, Pham.

Ma 123. Classification of Simple Lie Algebras. *9 units (3-0-6); third term. Prerequisites: Ma 5 or equivalent.* This course is an introduction to Lie algebras and the classification of the simple Lie algebras over the complex numbers. This will include Lie's theorem, Engel's theorem, the

solvable radical, and the Cartan Killing trace form. The classification of simple Lie algebras proceeds in terms of the associated reflection groups and a classification of them in terms of their Dynkin diagrams. Not offered 2025-26.

Ma 124. Elliptic Curves. *9 units (3-0-6); second term. Prerequisites: Ma 5 or equivalent.* The ubiquitous elliptic curves will be analyzed from elementary, geometric, and arithmetic points of view. Possible topics are the group structure via the chord-and-tangent method, the Nagel-Lutz procedure for finding division points, Mordell's theorem on the finite generation of rational points, points over finite fields through a special case treated by Gauss, Lenstra's factoring algorithm, integral points. Other topics may include diophantine approximation and complex multiplication. Not offered 2025-26.

Ma 125. Algebraic Curves. *9 units (3-0-6); third term. Prerequisites: Ma 5.* An elementary introduction to the theory of algebraic curves. Topics to be covered will include affine and projective curves, smoothness and singularities, function fields, linear series, and the Riemann-Roch theorem. Possible additional topics would include Riemann surfaces, branched coverings and monodromy, arithmetic questions, introduction to moduli of curves. Instructor: El-Maazouz.

EE/Ma/CS 126 ab. Information Theory. *9 units (3-0-6);* For course description, see Electrical Engineering

EE/Ma/CS/IDS 127. Error-Correcting Codes. *9 units (3-0-6);* For course description, see Electrical Engineering

Ma 128. Homological Algebra. *9 units (3-0-6); third term. Prerequisites: Math 120 abc or instructor's permission.* This course introduces standard concepts and techniques in homological algebra. Topics will include Abelian and additive categories; Chain complexes, homotopies and the homotopy category; Derived functors; Yoneda extension and its ring structure; Homological dimension and Koszul complexe; Spectral sequences; Triangulated categories, and the derived category. Not offered 2025-26.

Ma 130 abc. Algebraic Geometry. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 120 (or Ma 5 plus additional reading).* Plane curves, rational functions, affine and projective varieties, products, local properties, birational maps, divisors, differentials, intersection numbers, schemes, sheaves, general varieties, vector bundles, coherent sheaves, curves and surfaces. Instructors: Xu, Graber.

Ma 132 abc. Topics in Algebraic Geometry. *9 units (3-0-6); third term. Prerequisites: Ma 130 or instructor's permission.* This course will cover advanced topics in algebraic geometry that will vary from year to year. Topics will be listed on the math option website prior to the start of classes. Previous topics have included geometric invariant theory, moduli of curves, logarithmic geometry, Hodge theory, and toric

varieties. This course can be repeated for credit. Not offered 2025-26.

Ma 135 ab. Arithmetic Geometry. *9 units (3-0-6); first term. Prerequisites: Ma 130.* The course deals with aspects of algebraic geometry that have been found useful for number theoretic applications. Topics will be chosen from the following: general cohomology theories (étale cohomology, flat cohomology, motivic cohomology, or p-adic Hodge theory), curves and Abelian varieties over arithmetic schemes, moduli spaces, Diophantine geometry, algebraic cycles. Not offered 2025-26.

EE/Ma/CS/IDS 136. Information Measures and Applications. *9 units (3-0-6);* For course description, see Electrical Engineering

Ma/ACM/IDS 140 abc. Probability. *9 units (3-0-6); first, second, third terms. Prerequisites: For 140 a, Ma 108 b is strongly recommended.* This course begins with an overview of measure theory, followed by topics that include random walks, the strong law of large numbers, the central limit theorem, martingales, Markov chains, characteristic functions, Poisson processes, and Brownian motion. Towards the end, some further topics may be covered, such as stochastic calculus, stochastic differential equations, Gaussian processes, random graphs, Markov chain mixing, random matrix theory, and interacting particle systems. Instructors: Tamuz, El-Maazouz, Zhang.

Ma/ACM 142 ab. Ordinary and Partial Differential Equations. *9 units (3-0-6); second term. Prerequisites: Ma 108; Ma 109 is desirable.* The mathematical theory of ordinary and partial differential equations, including a discussion of elliptic regularity, maximal principles, solubility of equations. The method of characteristics. Part b not offered 2025-26. Instructor: Isett.

Ma 145 abc. Topics in Representation Theory. *9 units (3-0-6); second term. Prerequisites: Ma 5.* This course will discuss the study of representations of a group (or related algebra) by linear transformations of a vector space. Topics will vary from year to year, and may include modular representation theory (representations of finite groups in finite characteristic), complex representations of specific families of groups (esp. the symmetric group) and unitary representations (and structure theory) of compact groups. Not offered 2025-26.

Ma 146 ab. Introduction to Knot Theory and Quantum Topology. *9 units (3-0-6); first, second terms. Prerequisites: Ma 109 or equivalent.* Part a offers an introduction to knot theory: the problem of classification of knots, different knot types, basic (classical) invariants, and some elements of knot concordance. Part b moves from classical to quantum invariants: the Jones polynomial, colored Jones polynomial, and then more general quantum group invariants of knots and 3-manifolds. Part b also includes introduction to R-matrices, the Yang-Baxter equation, the Drinfeld-Kohno theorem and, if time permits, elements of categorification. Not offered 2025-26.

Ma 147 abc. Dynamical Systems. *9 units (3-0-6); second, third terms. Prerequisites: Ma 108, Ma 109, or equivalent.* First term: real dynamics and ergodic theory. Second term: Hamiltonian dynamics. Third term: complex dynamics. Not offered 2025-26.

Ma 148 ab. Topics in Mathematical Physics. *9 units (3-0-6); third term.* This course covers a range of topics in mathematical physics. The content will vary from year to year. Topics covered will include some of the following: Lagrangian and Hamiltonian formalism of classical mechanics; mathematical aspects of quantum mechanics: Schroedinger equation, spectral theory of unbounded operators, representation theoretic aspects; partial differential equations of mathematical physics (wave, heat, Maxwell, etc.); rigorous results in classical and/or quantum statistical mechanics; mathematical aspects of quantum field theory; general relativity for mathematicians. Geometric theory of quantum information and quantum entanglement based on information geometry and entropy. Part b not offered 2025-26. Instructor: Looi.

Ma 151 abc. Geometry and Topology. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 109 abc or equivalent.* Part a: Homology Theory. CW complexes, homology and calculation of homology groups, exact sequences, cohomology rings, Poincare duality. Part b: Homotopy Theory and K-theory. Fibrations, higher homotopy groups, and exact sequences of fibrations. Fiber bundles, Eilenberg-MacLane spaces, classifying spaces. K-theory, generalized cohomology theory, Bott periodicity. Part c: Basic Riemannian geometry: geometry of Riemannian manifolds, connections, curvature, Bianchi identities, completeness, geodesics, exponential map, Gauss's lemma, Jacobi fields, comparison theorems, relation between curvature and topology. Instructors: Ni, Chen, Caniato.

Ma 157 abc. Topics in Geometry and Topology. *9 units (3-0-6); first, second terms. Prerequisites: Ma 151 or equivalent, or instructor's permission.* Part a: Characteristic classes. Stiefel--Whitney classes, Chern classes, Pontryagin classes, cobordism theory, Chern--Weil theory. Part b and c: Basic topics may vary from year to year and may include elements of Morse theory and the calculus of variations, locally symmetric spaces, special geometry, comparison theorems, relation between curvature and topology, metric functionals and flows, geometry in low dimensions. Part c not offered 2025-26. Instructors: Chen, Song.

Ma 160 abc. Number Theory. *9 units (3-0-6); first, second, third terms. Prerequisites: Ma 5.* In this course, the basic structures and results of algebraic number theory will be systematically introduced. Topics covered will include the theory of ideals/divisors in Dedekind domains, Dirichlet unit theorem and the class group, p-adic fields, ramification, Abelian extensions of local and global fields. Instructors: Fu, Yang, Flach.

Ma 162 ab. Topics in Number Theory. *9 units (3-0-6); second term. Prerequisites: Ma 160.* The course will discuss in detail some advanced topics in number theory, selected from the following: Galois representations, elliptic curves, modular forms, L-functions, special values, automorphic representations, p-adic theories, theta functions, regulators. Part b not offered 2025-26. Instructor: Dimitrov.

Ma 191 abc. Selected Topics in Mathematics. *9 units (3-0-6); first, second, third terms.* Each term we expect to give between 0 and 6 (most often 2-3) topics courses in advanced mathematics covering an area of current research interest. These courses will be given as sections of 191. Students may register for this course multiple times even for multiple sections in a single term. The topics and instructors for each term and course descriptions will be listed on the math option website each term prior to the start of registration for that term. Instructors: T. Yu, Pham, Zhang, Yang, Heinaevaara, Looi, Svoboda, Marcolli, El-Maazouz, Flach, Dong.

SS/Ma 214. Mathematical Finance. *9 units (3-0-6);* For course description, see Social Science

Ma 290. Reading. *Hours and units by arrangement;* Occasionally, advanced work is given through a reading course under the direction of an instructor.

Ma 390. Research. *Units by arrangement;*

MECHANICAL ENGINEERING

EE/ME 7. Introduction to Mechatronics. *6 units (2-3-1);* For course description, see Electrical Engineering

ME 8. Introduction to Robotics. *6 units (1-4-1); first term. Prerequisites: Basic python programming, evidenced by the successful completion of a programming exercise by the end of the first week of classes. Open only to first year students. Sophomore students by permission of the instructor.* This course examines the range of concepts and engineering approaches applicable to robotics. This includes tools from mechanical design and fabrication, mathematical analysis of mechanisms, a variety of sensors, programming at all levels, algorithms to interpret visual images, and planners to determine actions. Robots also act in a larger context, involving human-robot interactions, social cues, and even raising ethical questions. The course will explore these topics through hardware and software mini-projects. Lab work will combine instructor-led, mandatory sessions with additional self-paced times. Instructor: Niemeyer.

ME 10. Thinking Like an Engineer. *1 unit; first term.* A series of weekly seminars by practicing engineers in industry and academia to introduce

students to principles and techniques useful for Mechanical Engineering. The course can be used to learn more about the different areas of study within Mechanical Engineering. Topics will be presented at an informal, introductory level. Required for ME undergraduates. Graded pass/fail. Instructor: Colonius.

ME 11 abc. Thermal Science. *9 units (3-0-6); first, second, third terms. Prerequisites: Sophomore standing required; ME 12 abc, may be taken concurrently.* An introduction to classical thermodynamics and transport with engineering applications. First and second laws; closed and open systems; properties of a pure substance; availability and irreversibility; generalized thermodynamic relations; gas and vapor power cycles; propulsion; mixtures; combustion and thermochemistry; chemical equilibrium; momentum and heat transfer including boundary layers with applications to internal and external flows. Not offered on a pass/fail basis. Instructors: Hunt, Blanquart, Fu.

ME 12 abc. Mechanics. *9 units (3-0-6); first, second, third terms. Prerequisites: Sophomore standing required; ME 11 abc, may be taken concurrently.* An introduction to statics and dynamics of rigid bodies, deformable bodies, and fluids. Equilibrium of force systems, principle of virtual work, distributed force systems, friction, static analysis of rigid and deformable structures, hydrostatics, kinematics, particle dynamics, rigid-body dynamics, Euler's equations, ideal flow, vorticity, viscous stresses in fluids, dynamics of deformable systems, waves in fluids and solids. Not offered on a pass/fail basis. Instructors: Mello, Andrade, Mello.

ME 13/113. Mechanical Prototyping. *4 units (0-4-0); first, second, summer terms.* Enrollment is limited and is based on responses to a questionnaire available in the Registrar's Office. Introduction to the technologies and practices needed to fabricate mechanical prototypes. Students will acquire the fundamental skills necessary to begin using 3D Computer-Aided Design (CAD) software. Students will learn how to build parametric models of parts and assemblies and learn how to generate detailed drawings of their designs. Students will also be introduced to manual machining techniques, as well as computer-controlled prototyping technologies, such as three-dimensional printing, laser cutting, and water jet cutting. Students will receive safety-training, instruction on the theories underlying different machining methods, and hands-on demonstrations of machining and mechanical assembly methods. Several prototypes will be constructed using the various technologies available in the Mechanical Engineering Machine Shop. Instructors: Stovall, Wilson.

ME 14. Design and Fabrication. *9 units (3-5-1); third term. Prerequisites: ME 12 ab, ME 13.* Enrollment is limited and is based on responses to a questionnaire available in the Registrar's office. Introduction to mechanical engineering design, fabrication, and visual communication. Principles of mechanical engineering design are taught through a series of lectures and short group-based design projects with an emphasis on

formal design reviews and team competitions. Course lectures address the strength properties of engineering materials, statistical descriptions of stress and strength, design safety factors, static and variable loading design criteria, engineering case studies, and the design of mechanical elements. Group-based projects include formal design reviews and involve substantial use of the machine shop and maker-space facilities, for the construction of working prototypes. Not offered on a pass/fail basis. Instructor: Staff.

ME 23/123. CNC Machining. *4 units (0-4-0); third, summer terms. Prerequisites: ME 13/113.* Enrollment is limited and is based on responses to a questionnaire available in the Registrar's office. Introduction to computer numerical control machining. Students will learn to create Gcode and Mcode using Computer-Aided Manufacturing (CAM) software; they will be instructed on how to safely prepare and operate the machine's functions; and will be taught how to implement programmed data into several different types of CNC equipment. The class will cover the parts and terminology of the equipment, fixturing materials, setting workpiece, and tool offsets. Weekly assignments will include the use of CAM software, machine operation demonstrations, and machining projects. Instructors: Stovall, Wilson.

ME 40. Dimensional and Data Analyses in Engineering. *9 units (3-0-6); first term. Prerequisites: Ma 1 abc, ME 11 abc, ME 12 abc.* The first part of this course covers the application of symmetry and dimensional homogeneity (Buckingham Pi theorem) to engineering analysis of systems. The important role of dimensional analysis in developing empirical theories, designing experiments and computer models, and analyzing data are stressed. The second part of the course focuses on quantitative data analysis including linear regression, least-squares, principle components, Fourier analysis, and Bayesian methods. The underlying theory is briefly covered, but the focus is on application to real-world problems encountered by mechanical engineers. Applications to uncertainty analysis and quantification are discussed. Homework will include implementation of techniques in Matlab. Instructor: Blanquart.

ME 50 ab. Experiments and Modeling in Mechanical Engineering. *12 units (3-6-3); second, third terms. Prerequisites: ME 11 abc, ME 12 abc, ME 13, ME 14, and programming skills at the level of ACM 11.*
Two-quarter course sequence covers the general theory and methods of computational fluid dynamics (CFD) and finite element analysis (FEA) with experimental laboratory methods applied to complementary engineering problems in solid, structural, and fluid mechanics. Computational procedures are discussed and applied to the analysis of steady-state, transient, and dynamic problems using a commercial software. CFD and FEA topics covered include meshing, types of elements, steady and unsteady solvers, inviscid and viscous flow, internal and external flow, drag and lift, static and dynamic mechanical loading, elastic and plastic behavior, and vibrational (modal) analysis. Fluid mechanics laboratory experiments introduce students to the operation of a water tunnel combined with laser particle image

velocimetry (PIV) for quantified flow field visualization of velocity and vorticity. Solid mechanics experiments introduce students to the operation of a mechanical (axial/torsional) load frame combined with digital image correlation (DIC) and strain gage transducers for quantification and full field visualization of displacement and strain. Technical writing skills are emphasized through the generation of detailed full-length lab reports using a scientific journal format. Instructor: Mello.

ME 72 ab. Engineering Design Laboratory. *12 units (2-8-2) first term; 15 units (1-13-1) second term; first, second terms. Prerequisites: ME 14.* Enrollment is limited. A project-based course in which teams of students are challenged to design, test, analyze, and fabricate a robotic device to compete against devices designed by other student teams. The class lectures and team projects stress the integration of mechanical design, electronics, mechatronics, engineering analysis, and computation to solve problems in engineering system design. Critical feedback is provided through a series of formal design reviews scheduled throughout the ME 72 ab course sequence. The laboratory units of ME 72 can be used to fulfill a portion of the laboratory requirement for the EAS option. Not offered on a pass/fail basis. Instructors: Mello, Stovall.

CS/EE/ME 75 abc. Multidisciplinary Systems Engineering. *3 units (2-0-1), 6 units (2-0-4), or 9 units (2-0-7) first term; 6 units (2-3-1), 9 units (2-6-1), or 12 units (2-9-1) second and third terms;* For course description, see Computer Science

ME 90 abc. Senior Thesis: Major Design Experience. *9 units (0-0-9); first, second, third terms. Prerequisites: senior status; instructor's permission.* Students complete a senior thesis that includes a major design experience (as required for the ME degree). The major design experience builds on the knowledge and skills acquired in earlier coursework and incorporates appropriate engineering design standards and multiple design constraints. The thesis is supervised by an engineering faculty member. The topic selection is determined by the adviser and the student and is subject to approval by the Mechanical Engineering Undergraduate Committee. First and second terms: midterm progress report and oral presentation during finals week. Third term: completion of thesis and final presentation. Not offered on pass/fail basis. Instructor: Ames.

ME 91 abc. Senior Thesis. *9 units (0-0-9); first, second, third terms. Prerequisites: senior status; instructor's permission.* Students complete a senior thesis involving research in mechanical engineering; the thesis is supervised by an engineering faculty member. The topic selection is determined by the adviser and the student and is subject to approval by the Mechanical Engineering Undergraduate Committee. First and second terms: midterm progress report and oral presentation during finals week. Third term: completion of thesis and final presentation. Not offered on a pass/fail basis. Instructor: Ames.

ME 100. Independent Studies in Mechanical Engineering. *Units are assigned in accordance with work accomplished;* A faculty mentor will oversee a student proposed, independent research or study project to meet the needs of undergraduate students. Graded pass/fail. The consent of a faculty mentor and a written report is required for each term of work.

Ae/APh/CE/ME 101 abc. Fluid Mechanics. *9 units (3-0-6);* For course description, see Aerospace

Ae/AM/CE/ME 102 abc. Mechanics of Structures and Solids. *9 units (3-0-6);* For course description, see Aerospace

APh/MS/ME 105 abc. States of Matter. *9 units (3-0-6);* For course description, see Applied Physics

E/ME/MedE 106 ab. Design for Freedom from Disability. *9 units (3-0-6);* For course description, see Engineering

ME 110. Special Laboratory Work in Mechanical Engineering. *3-9 units per term; maximum two terms.* Special laboratory work or experimental research projects may be arranged by members of the faculty to meet the needs of individual students as appropriate. A written report is required for each term of work. Instructor: Staff.

ChE/ESE/ME/MS 111. Sustainable Engineering. *9 units (3-0-6);* For course description, see Chemical Engineering

MS/ME/MedE 116. Mechanical Behavior of Materials. *9 units (3-0-6);* For course description, see Materials Science

ME/EE/EST 117. Energy Technology and Policy. *9 units (3-0-6); second term. Prerequisites: Ph 1 abc, Ch 1 ab and Ma 1 abc.* Energy technologies and the impact of government policy. Fossil fuels, nuclear power, and renewables for electricity production and transportation. Resource models and climate change policies. New and emerging technologies. Instructor: Hunt.

Ae/ME 118. Classical Thermodynamics. *9 units (3-0-6);* For course description, see Aerospace

ME 119. Heat and Mass Transfer. *9 units (3-0-6); third term. Prerequisites: ME 11 abc, ME 12 abc, ACM 95/100 (may be taken concurrently).* Transport properties, conservation equations, conduction heat transfer, convective heat and mass transport in laminar and turbulent flows, phase change processes, thermal radiation. Not offered 2025-26.

ME/Ae 120. Combustion Fundamentals. *9 units (3-0-6); third term. Prerequisites: ME 11 abc or equivalent, ACM 95/100 or equivalent (may be taken concurrently).* The course will cover chemical equilibrium,

chemical kinetics, combustion chemistry, transport phenomena, and the governing equations for multicomponent gas mixtures. Topics will be chosen from non-premixed and premixed flames, laminar and turbulent flames, combustion-generated pollutants, and numerical simulations of reacting flows. Not offered 2025-26. .

ME/CS/EE 129. Experimental Robotics. *9 units (1-7-1); third term. Prerequisites: some experience with (i) Python programming (CS1, CS2, or equivalent), (ii) Hardware, Sensors, and Signal Processing (EE/ME7, ME8, EE1, or similar), and/or (iii) Robotic Devices (ME13, ME72, or related), as evidenced to the instructor. Not recommended for first-year students.* This course covers the foundations of experimental realization on robotic systems. This includes software infrastructure to operate physical hardware, integrate various sensor modalities, and create robust autonomous behaviors. Using the Python programming language, assignments will explore techniques from simple polling, interrupt driven and multi-threaded architectures, to detecting events in unreliable sensor data, observing the state of the world, building up maps, and ultimately planning strategies. Developments will be integrated on mobile robotic systems and demonstrated weekly, leading up to a final autonomous, multi-robot challenge. Please be prepared to form teams of two at the organizational meeting. Instructor: Niemeyer.

ME/CS/EE 133 ab. Robotics. *9 units (3-2-4); first, second terms. Prerequisites: ME/CS/EE 129, or Python programming experience, evidenced to instructor.* The course develops the core concepts of robotics. The first quarter focuses on classical robotic manipulation, including topics in rigid body kinematics and dynamics. It develops planar and 3D kinematic formulations and algorithms for forward and inverse computations, Jacobians, and manipulability. The second quarter transitions to planning, navigation, and perception. Topics include A* and D* graph search, roadmap, sample-based RRT and EST planning, as well as localization and mapping algorithms, to achieve collision-free motions. Course work transitions from homework and programming assignments to more open-ended team-based projects. Instructor: Niemeyer.

ME/CS/EE 134. Robotic Systems. *9 units (1-7-1); second term. Prerequisites: ME/CS/EE 133 a, or with permission of instructor.* This course builds up, and brings to practice, the elements of robotic systems at the intersection of hardware, kinematics and control, computer vision, and autonomous behaviors. It presents selected topics from these domains, focusing on their integration into a full sense-think-act robot. The lectures will drive team-based projects, progressing from building custom robotic arms (5 to 7 degrees of freedom) to writing all necessary software (utilizing the Robotics Operating system, ROS). Teams are required to implement and customize general concepts for their selected tasks. Working systems will autonomously operate and demonstrate their capabilities during final presentations. Please be prepared to form teams of three or four at the organizational meeting. Instructor: Niemeyer.

ME/CE/Ge/ESE 146. Computational Methods for Flow in Porous Media. *9 units (3-0-6); second term. Prerequisites: ME 11 abc, ME 12 abc, ACM 95/100, ACM 106 ab (may be taken concurrently).* This course covers physical, mathematical, and simulation aspects of single and two-phase flow and transport through porous media. Conservation equations for multiphase, multicomponent flow. Modeling of fluid mechanical instabilities such as viscous fingering and density-driven convection. Coupling fluid flow with chemical reactions and heat transfer. Numerical methods for elliptic equations: finite volume methods, two-point flux approximations. Numerical methods for hyperbolic equations: high-order explicit methods, implicit method. Applications in hydrology, geological CO2 sequestration, and induced seismicity, among others, will be demonstrated. Instructor: Fu.

AM/CE/ME 150 abc. Graduate Engineering Seminar. *1 unit;* For course description, see Applied Mechanics

Ae/Ge/ME 160 ab. Continuum Mechanics of Fluids and Solids. *9 units (3-0-6);* For course description, see Aerospace

MS/ME 161. Imperfections in Crystals. *9 units (3-0-6);* For course description, see Materials Science

AM/ME 165. Finite Elasticity. *9 units (3-0-6);* For course description, see Applied Mechanics

MS/ME 166. Fracture of Brittle Solids. *9 units (3-0-6);* For course description, see Materials Science

ME/CS/EE 169. Mobile Robots. *9 units (1-7-1); third term. Prerequisites: ME/CS/EE 133 b, or with permission of instructor.* Mobile robots need to perceive their environment and localize themselves with respect to maps thereof. They further require planners to move along collision-free paths. This course builds up mobile robots in team-based projects. Teams will write all necessary software from low-level hardware I/O to high level algorithms, using the robotic operating system (ROS). The final systems will autonomously maneuver to reach their goals or track various objectives. Please be prepared to form teams of two at the organizational meeting. Instructor: Niemeyer.

ME/CE/Ge 174. Mechanics of Rocks. *9 units (3-0-6); second term. Prerequisites: Ae/Ge/ME 160 a.* Basic principles of deformation, strength, and stressing of rocks. Elastic behavior, plasticity, viscoelasticity, viscoplasticity, creep, damage, friction, failure mechanisms, shear localization, and interaction of deformation processes with fluids. Engineering and geological applications. Instructor: Lapusta.

ESE/ME/EST/Ec/ChE/EE 179. Climate Change Impacts, Mitigation and Adaptation. *3 units (3-0-0);* For course description, see

ME 200. Advanced Work in Mechanical Engineering. *;* A faculty mentor will oversee a student proposed, independent research or study project to meet the needs of graduate students. Graded pass/fail. The consent of a faculty mentor and a written report is required for each term of work.

ME 201. Advanced Topics in Mechanical Engineering. *9 units (3-0-6); third term.* The faculty will prepare courses on advanced topics to meet the needs of graduate students. Instructor: Andrade.

Ae/AM/MS/ME 213. Mechanics and Materials Aspects of Fracture. *9 units (3-0-6);* For course description, see Aerospace

Ae/AM/CE/ME 214. Computational Solid Mechanics. *9 units (3-5-1);* For course description, see Aerospace

Ae/AM/ME 215. Dynamic Behavior of Materials. *9 units (3-0-6);* For course description, see Aerospace

Ae/ME/APh 218. Statistical Mechanics. *9 units (3-0-6);* For course description, see Aerospace

ME/MS/AM 221. Effective properties of heterogenous and meta-materials. *9 units (3-0-6); third term. Prerequisites: Ae/AM/CE/ME 102 or equivalent.* Heterogenous materials. Notion of effective properties. Homogenization theory and applications to linear conductivity, elasticity and viscoelasticity. Effective properties in non-linear setting and instabilities. Wave propagation and meta-materials. Bandgaps. Not offered 2025-26.

Ae/AM/ME 223. Plasticity. *9 units (3-0-6);* For course description, see Aerospace

ME/MS/Ae/AM 224. Multifunctional Materials. *9 units (3-0-6); third term. Prerequisites: MS 115 or equivalent, Ae/AM/CE/ME 102 abc or APh 105 abc (may be waived with instructor's permission).* Multiscale view of materials and different approaches of introducing functionality; Electronic aspects and multiferroic materials; Symmetry breaking phase transformations, microstructure: shape-memory alloys, ferroelectrics, liquid crystal elastomers; Composite materials and metamaterials: multifunctional structures. Not offered 2025-26.

Ae/AM/ME/Ge 225. Special Topics in Solid Mechanics. *Units to be arranged;* For course description, see Aerospace

Ae/ACM/ME 232 ab. Computational Fluid Dynamics. *9 units (3-0-6);* For course description, see Aerospace

ME/CDS/EE 234 ab. Advanced Robotics: Planning. *9 units (3-3-3); second, third terms. Prerequisites: ME/CS/EE 133 b, or equivalent.*

ME/CS/EE 133 a preferred. Advanced topics in robotic motion planning and navigation, including inertial navigation, simultaneous localization and mapping, Markov Decision Processes, Stochastic Receding Horizon Control, Risk-Aware planning, robotic coverage planning, and multi-robot coordination. Course work will consist of homework, programming projects, and labs. Given in alternate years. Not offered 2025-26.

ME/CDS/EE 235 ab. Advanced Robotics: Kinematics. *9 units (3-3-3); second, third terms. Prerequisites: ME/CS/EE 133 a, or equivalent.* Advanced topics in robot kinematics and robotic mechanisms. Topics include a Lie Algebraic viewpoint on kinematics and robot dynamics, a review of robotic mechanisms, and a detailed development of robotic grasping and manipulation. Given in alternate years. Instructor: Burdick.

Ae/CDS/ME 251 ab. Closed Loop Flow Control. *9 units (3-0-6 a, 1-6-1 b);* For course description, see Aerospace

AM/CE/ME 252. Linear and Nonlinear Waves in Structured Media. *9 units (2-1-6);* For course description, see Applied Mechanics

Ae/AM/CE/ME/Ge 265 ab. Static and Dynamic Failure of Brittle Solids and Interfaces, from the Micro to the Mega. *9 units (3-0-6);* For course description, see Aerospace

ME/Ge/Ae 266 ab. Fracture and Frictional Faulting. *9 units (3-0-6); second. Prerequisites: Ae/AM/CE/ME 102 a or Ae/Ge/ME 160 a or instructor's permission.* Introduction to elastodynamics and waves in solids. Fracture theory, energy concepts, cohesive zone models. Friction laws, nucleation of frictional instabilities, rupture of frictional interfaces. Radiation from moving cracks. Thermal effects during dynamic fracture and faulting. Interaction of faulting with fluids. Applications to engineering phenomena a physics and mechanics of earthquakes. Not offered 2025-26.

ME 300. Research in Mechanical Engineering. *Hours and units by arrangement;* Research in the field of mechanical engineering. By arrangement with members of the faculty, properly qualified graduate students are directed in research.

MEDICAL ENGINEERING

MedE 99. Undergraduate Research in Medical Engineering. *Variable units as arranged with the advising faculty member; first, second, third terms.* Undergraduate research with a written report at the end of each term; supervised by a Caltech faculty member, or co-advised by a Caltech faculty member and an external researcher. Graded pass/fail. Instructor: Staff.

MedE 100 abc. Medical Engineering Seminar. *1 unit; first, second, third terms.* All PhD degree candidates in Medical Engineering are required to attend all MedE seminars. If there is no MedE seminar during a week, then the students should go to any other graduate-level seminar that week. Students should broaden their knowledge of the engineering principles and sciences of medical engineering. Students are expected to learn the forefronts of the research and development of medical materials, technologies, devices and systems from the seminars. Graded pass/fail. Instructors: Gao, Wang.

MedE 101 A. Fundamentals of Medical Physiology. *9 units (3-0-6); first term. Prerequisites: No Prerequisites required, Bi 1 or equivalent recommended.* This course explores the functions of the human body, focusing on normal physiological processes and selected diseases. Organized by major organ systems-Muscle, nervous, cardiovascular, renal, respiratory, gastrointestinal, and endocrine-the course examines their functions and interactions in maintaining homeostasis. Students will develop a foundational understanding of physiological functions from the subcellular to whole-body level, analyze feedback control mechanisms, and apply their knowledge to assess health and disease. This course prepares students for advanced studies in medical and health-related fields. Instructor: Anqi Zhang.

MedE 101 B. Introduction to Clinical Physiology and Pathophysiology for Engineers. *9 units (3-0-6); third term. Prerequisites: No Prerequisites, Bi 1 or equivalent recommended.* The goal of this course is to introduce engineering scientists to medical physiological systems: with a special emphasis on the clinical relevance. The design of the course is to present two related lectures each week: An overview of the physiology of a system followed by examples of current clinical medical challenges and research highlighting diagnostic and therapeutic modalities. The final three weeks of the course will be a mini workshop where the class explores challenging problems in medical physiology. The course ultimately seeks to promote a bridge between relevant clinical problems and engineering scientists who desire to solve them. Graded pass/fail. Instructor: Staff.

E/ME/MedE 106 ab. Design for Freedom from Disability. *9 units (3-0-6);* For course description, see Engineering

ChE/BE/MedE 112. Enhancing Technical Creativity with AI Tools in the Context of Microfluidics for Global Health. *9 units (3-0-6);* For course description, see Chemical Engineering

EE/MedE 114 ab. Analog Circuit Design. *12 units (4-0-8);* For course description, see Electrical Engineering

EE/MedE 115. Micro-/Nano-scales Electro-Optics. *9 units (3-0-6);* For course description, see Electrical Engineering

MS/ME/MedE 116. Mechanical Behavior of Materials. *9 units (3-0-6);* For course description, see Materials Science

EE/MedE 124. Mixed-mode Integrated Circuits. *9 units (3-0-6);* For course description, see Electrical Engineering

EE/CS/MedE 125. Digital Circuit Design with FPGAs and VHDL. *9 units (3-6-0);* For course description, see Electrical Engineering

MedE/EE/BE 168 abc. Biomedical Optics: Principles and Imaging. *9 units (4-0-5) each; second term, part a offered 2027-2028, part b offered 2025-26, part c offered 2026-27.. Prerequisites: instructor's permission.* Part a covers the principles of optical photon transport in biological tissue. Topics include a brief introduction to biomedical optics, single-scatterer theories, Monte Carlo modeling of photon transport, convolution for broad-beam responses, radiative transfer equation and diffusion theory, hybrid Monte Carlo method and diffusion theory, and sensing of optical properties and spectroscopy, (absorption, elastic scattering, Raman scattering, and fluorescence). Part b covers established optical imaging technologies. Topics include ballistic imaging (confocal microscopy, two-photon microscopy, super-resolution microscopy, etc.), optical coherence tomography, Mueller optical coherence tomography, and diffuse optical tomography. Part c covers emerging optical imaging technologies. Topics include photoacoustic tomography, ultrasound-modulated optical tomography, optical time reversal (wavefront shaping/engineering), and ultrafast imaging. MedE/EE/BE 168b offered 2025-26. Instructor: Wang.

EE/CS/MedE 175. Advanced Topics in Digital Design with FPGAs and VHDL. *9 units (3-6-0);* For course description, see Electrical Engineering

EE/MedE 185. Micro/Nano Technology for Semiconductor and Medical Device. *9 units (3-0-6);* For course description, see Electrical Engineering

EE/MedE 187. MEMS/NEMS Technologies for Biomedical Devices. *9 units (3-0-6);* For course description, see Electrical Engineering

ChE/BE/MedE 188. Molecular Imaging. *9 units (3-0-6);* For course description, see Chemical Engineering

BE/EE/MedE 189. Design and Construction of Biodevices. *12 units (3-6-3);* For course description, see Bioengineering

MedE 199. Special Topics in Medical Engineering. *Units to be arranged; terms to be arranged.* Subject matter will change from term to term depending upon staff and student interest, but will generally center on the understanding and applying engineering for medical problems. Instructor: Staff.

MedE 201. Introduction to Medical Devices. *9 units (3-0-6); second term.* This course provides a broad coverage on the frontiers of medical diagnostic and therapeutic technologies and devices based on multidisciplinary engineering principles. Topics include FDA regulations, in vitro diagnostics, biosensors, electrograms, medical imaging technologies, medical implants, nanomedicine, cardiovascular engineering & technology, medical electronics, wireless communications through the skin and tissue, and medical robotics. Overall, the course will cover the scientific fundamentals of biology, chemistry, engineering, physics, and materials specific to medical applications. However, both the lectures and assignments will also emphasize the design aspects of the topics as well as up-to-date literature study. Instructor: Gao.

MedE 202. Sensors in Medicine. *9 units (3-0-6); second term.* Sensors play a very important role in all aspect of modern life. This course is an essential introduction to a variety of physical, chemical and biological sensors that are used in medicine and healthcare. The fundamental recognition mechanisms, transduction principles and materials considerations for designing powerful sensing and biosensing devices will be covered. We will also discuss the development of emerging electronic-skin, wearable and soft electronics toward personalized health monitoring. Participants in the course will develop proposals for novel sensing technologies to address the current medical needs. Instructor: Gao.

MedE/EE 204. Principles and Designs of Medical Neuromodulation Devices. *9 units (3-0-6); second term. Prerequisites: Instructor's permission.* This is a course for senior undergraduates and graduate students. This course provides a review for advanced medical neuromodulation devices based on multidisciplinary engineering principles. Emphasis will be on implantable neuromodulation devices for both neural recording and stimulation such as EKG, EEG, EMG, pacemakers, DBS, etc. Sub-topics include biomaterials, biocompatibility, medical electronics, and FDA regulation on medical devices. The course will focus on engineering fundamentals specific for neural applications. Lectures and assignments will emphasize the design aspects of various devices as well as up-to-date literature study. Instructor: Tai.

MedE 205. New Frontiers in Medical Technologies. *6 units (2-0-4); third term. Prerequisites: None but knowledge of semiconductor physics and some system engineering, basic electrical engineering highly recommended.* New Frontiers of Medical Technologies is an introductory graduate level course that describes space technologies, instruments, and engineering techniques with current and potential applications in medicine. These technologies have been originally and mainly developed for space exploration. Spinoff applications to medicine have been explored and proven with various degrees of success and maturity. This class introduces these topics, the basics of the technologies, their intended original space applications, and the medical applications. Topics include but are not limited to multimodal imaging, UV/Visible/NIR

imaging, imaging spectrometry, sensors, robotics, and navigation. Graded pass/fail. Not offered 2025-26. Instructor: Staff.

MedE/BE/Ae 243. Physiological Mechanics. *9 units (3-0-6); third term. Prerequisites: Ae/APh/CE/ME 101 abc or equivalent or ChE 103 a.* Internal flows: steady and pulsatile blood flow in compliant vessels, internal flows in organisms. Fluid dynamics of the human circulatory system: heart, veins, and arteries (microcirculation). Mass and momentum transport across membranes and endothelial layers. Fluid mechanics of the respiratory system. Renal circulation and circulatory system. Biological pumps. Low and High Reynolds number locomotion. Not offered 2025-26. Instructor: Staff.

MedE/EE 268. Medical Imaging. *9 units (4-0-5); second term.* Medical imaging technologies will be covered. Topics include X-ray radiography, X-ray computed tomography (CT), nuclear imaging (PET & SPECT), ultrasonic imaging, and magnetic resonance imaging (MRI). Not offered 2025-26. Instructor: Wang.

MedE 291. Research in Medical Engineering. *Units to be arranged; first, second, third terms.* Qualified graduate students are advised in medical engineering research, with the arrangement of MedE staff. Graded pass/fail.

MUSIC

Mu 52. Fundamentals of Western Music Theory. *9 units (3-0-6); first term.* Intended for students with no or limited musical training, this course is an introduction to the elements of Western music. We will practice reading, notating, and analyzing music through the study of rhythm and meter, scales, intervals, chords, and basic harmonic progressions; musical examples will be drawn from a variety historical periods and styles, including classical, pop, jazz, film, and musical theater. The final project will be a short musical composition. This can be a stand-alone course for students who want to understand how music is put together, or it can serve as preparation for those who might benefit from a review of the fundamentals before taking further courses in music theory. Not offered 2025-26.

Mu 53. Listening to Music. *9 units (3-0-6); second term.* Most of the music we encounter can be thought of as the organization of a very limited set of tones into distinct patterns of repetition, and it has been this way for hundreds, if not thousands, of years. And yet, music has come to mean infinitely more than its sonic surface: we study great works of music like we do great works of literature and art; we use our musical preferences to convey our social and political identities; we expect - and technology has enabled - our public and private spaces to be saturated in music; and certain musical works possess such power that they are sometimes altered, if not banned outright. But how has

music acquired all of these meanings? How does it communicate? What is it that we are listening to when we are listening to music? In addition to serving as an introduction to the academic study of music, this course aims to deepen our musical appreciation and understanding by critically examining listening habits of the past and present. Knowledge of Western music notation and harmony is helpful but not required; the basics will be reviewed as needed. Not offered 2025-26.

Mu 54. History and Theory of 20th-Century Music. *9 units (3-0-6); second term. Prerequisites: Mu 57 or the ability to read music and some knowledge of music theory fundamentals (scales, intervals, triads, and seventh chords).* This course surveys significant developments in classical music of the 20th century. From the impressionism of Debussy and Ravel at the beginning of the century to the minimalism of Steve Reich and Philip Glass at the end, we will study how 20th-century composers sought to create new ways of constructing music, often trying to distance themselves from the traditions of the past. We will explore specific compositional techniques that produced strikingly new sounds and styles, as well as the intellectual and historical contexts that shaped their development. Course activities include reading, listening, musical analysis, and guided composition. Instructor: Ballance.

Mu 55. The Great Orchestras: Their History, Conductors and Repertoire. *9 units (3-0-6); third term.* This survey course will trace the symphony orchestra from its origins in the mid eighteenth century to the present day. Special emphasis will be given to the great civic orchestras of the nineteenth and twentieth centuries, their conductors, and core orchestral repertoire. Making use of historic audio and video recordings from the twentieth century, along with more recent documentary recordings, students will be exposed to the cultural history of modern Europe and America through the medium of classical music. Not offered 2025-26.

Mu 56. Jazz History. *9 units (3-0-6); second term.* This course will examine the history of jazz in America from its roots in the unique confluence of racial and ethnic groups in New Orleans around 1900 to the present. The lives and music of major figures such as Robert Johnson, Jelly Roll Morton, Louis Armstrong, Benny Goodman, Duke Ellington, Count Basie, Charlie Parker, Dizzy Gillespie, Thelonius Monk, Miles Davis and others will be explored. Not offered 2025-26.

Mu 57. Fundamentals of Music Theory. *9 units (3-0-6); first term.* This skills-based course introduces students to the fundamentals of Western music theory. Considering a broad range of musical styles, we will explore the basic structures and relationships that have shaped music in the West through past centuries and into the present day. Through analysis, listening, practical exercises, and creative projects, we will gain fluency with the materials of music and develop a strong musical vocabulary. With these skills, we will be able to consider how different kinds of music are constructed and what makes them sound the way they do. Major topics for study include music notation, rhythm and

meter, scales and tonality, intervals, triads and seventh chords, and basic harmonic relationships. This class is suitable for students with little or no musical background, or for students with a performance background but no prior experience with music theory. Students do not need to be able to read music before taking this class. Instructor: Ballance.

Mu 58. Music Theory I. *9 units (3-0-6); second term. Prerequisites: Mu 57 or the ability to read music and have equivalent knowledge of music theory fundamentals (scales, intervals, triads, and seventh chords); Students with questions about the necessary background knowledge should contact instructor. A self-study option is available for review of theory fundamentals.* This course introduces the language and structure of tonal music, from the most basic musical phrase to the form of short pieces. Through this study, we will learn how harmonic relationships can create the sensation of movement, surprise, tension, or rest within a musical phrase, and we will especially consider how composers have used those tendencies to expressive effect. Course activities encompass both written work and aural skills: students will work with theoretical concepts through singing and aural analysis and well as through written analysis and composition exercises. Instructor: Ballance.

Mu 59. Music Theory II. *9 units (3-0-6); third term. Prerequisites: Mu 58 or AP Music Theory or equivalent strong background in diatonic harmony. Students with questions about the necessary background knowledge should contact instructor. A self-study option is available for diatonic harmony review.* This course builds on the frameworks developed in Mu 58 to explore elements of chromatic harmony in tonal music. Beginning with tonicization and modulation, we will develop the skills we need to analyze large musical forms, such as complete symphony or sonata movements. We will also delve into the harmonic language of the Romantic era and seek to understand the chromatic techniques that make this repertoire so colorful and expressive. Course activities include written and aural analysis, short composition exercises, and a final composition project. Instructor: Ballance.

Mu 135. Music and Storytelling. *9 units (3-0-6); third term. Prerequisites: This is a listening-based class that is appropriate for students with and without a musical background. The ability to read music will be helpful, but is not required.* Musicians and listeners have long been fascinated by the potential for music to portray something outside of itself: to tell a story, paint a picture, or suggest a narrative without using words. This course explores ways that composers have tried to express specific ideas through sound at various points in history. We will investigate the musical techniques composers have used in these efforts, as well as a variety of theories from the past and present about music and meaning. We will also consider the role of listener interpretation, including instances where listeners-perhaps even ourselves-have perceived stories and images in music that the composer did not intend. Music for study is drawn from historical eras ranging from the Renaissance to the present. Instructor: Ballance.

Mu 136. The Concerto Through History. *9 units (3-0-6); first term. Prerequisites: Students in this class will need to be able to read music. Some background in music theory will be helpful, but we will review as needed.* This course traces the history of the concerto genre, beginning with its origins in the late Renaissance and continuing into the 20th century. We will investigate how the form and structure of the concerto has changed over time, evolutions in the role of the concerto soloist, and the variety of functions the concerto has played in concert culture. We will consider individual concertos through musical analysis, as well as theoretical writings on concerto composition and historical records related to concerto performance. Students will be encouraged to nominate their favorite concertos for study in class. Instructor: Ballance.

Mu 137. Themes in Western Music History and Historiography: Pre-1600. *9 units (3-0-6); third term.* This course surveys the music and musical institutions of Ancient Greece, the Middle Ages, and the Renaissance. Nearly two millennia of musical developments, needless to say, cannot be adequately covered in ten weeks; the course thus aims to build literacy in music from these periods by contextualizing musical works and their creators against broader themes, including music and the church, music and politics, music and gender, the evolution of musical notation, and the rise of secular music. At the same time, we will interrogate the central historical narratives of Western music that we have inherited and grapple with how historiography - the writing of history - shapes the way we understand the musical past and present. Not offered 2025-26.

Mu 138. Themes in Western Music History and Historiography: 1600-1800. *9 units (3-0-6); first term.* This course surveys the music and musical institutions of Europe during the Baroque and Enlightenment eras. Two hundred years of musical developments, needless to say, cannot be adequately covered in ten weeks; the course thus aims to build literacy in music from these periods by contextualizing musical works and their creators against broader themes, including music in the European courts, music and religion, words and music, music and gender, music and Enlightenment ideals, and the rise of instrumental music. At the same time, we will interrogate the central historical narratives of Western music that we have inherited and grapple with how historiography - the writing of history - shapes the way we understand the musical past and present. Not offered 2025-26.

Mu 139. Themes in Western Music History and Historiography: 1800-Present. *9 units (3-0-6); second term.* This course surveys the music and musical institutions of the so-called "Western art music" tradition from the Romantic era until the present. Over two hundred years of musical developments, needless to say, cannot be adequately covered in ten weeks; the course thus aims to build literacy in music of this period by contextualizing musical works and their creators against broader themes, including music and the nation, music as art and philosophy, music and appropriation, music and genre, and the musical

canon. At the same time, we will interrogate the central historical narratives of Western music that we have inherited and grapple with how historiography - the writing of history - shapes the way we understand the musical past and present. Not offered 2025-26.

Mu 150. Special Topics in Music. *9 units (3-0-6); Offered by announcement.* An advanced humanities course on a special topic in music. Topics may include specific genres of music, the music of particular eras or geographical regions, or the relationship between music and other aspects of culture. The course may be re-taken for credit except as noted in the course announcement. See registrar's announcement for details. Instructors: Staff, visitor.

NEUROBIOLOGY

NB 101. Survey of Neurobiology Research at Caltech. *1 unit; first term.* This course is designed to introduce undergraduate NB minors and first-year NB graduate students to the variety of research being undertaken by NB faculty. Topics from all the neurobiology-related research labs are discussed and span the range from single molecules to behavior to neuroscience-related aspects of public health. Instructor: Lester.

NB/Bi/CNS 150. Introduction to Neuroscience. *10 units (4-0-6); third term. Prerequisites: Bi 8, 9, or instructor's permission.* General principles of the function and organization of nervous systems, providing both an overview of the subject and a foundation for advanced courses. Topics include the physical and chemical bases for action potentials, synaptic transmission, and sensory transduction; anatomy; development; sensory and motor pathways; memory and learning at the molecular, cellular, and systems level; and the neuroscience of brain diseases. Letter grades only. Instructors: Lester, Adolphs.

NB/Bi/CNS 152. Neural Circuits and Physiology of Homeostatic Regulation. *6 units (2-0-4); second term. Prerequisites: Graduate standing or NB/Bi/CNS 150, or equivalent.* An advanced course of lectures, readings, and student presentations focusing on neural basis of innate body functions such as appetite, sleep, temperature, and osmolality regulation. This course will also cover the gut-to-brain interactions focusing on homeostatic functions. These include genetics, neural manipulation, and viral tracing tools with particular emphasis on data interpretation and limitation of available neuroscience tools. Given in alternate years; not offered 2025-26. Instructor: Oka.

NB/Bi/CNS 154. Principles of Neuroscience. *9 units (3-0-6); third term. Prerequisites: NB/Bi/CNS 150 or equivalent.* This course aims to distill the fundamental tenets of brain science, unlike the voluminous textbook with a similar title. What are the essential facts and ways of understanding in this discipline? How does neuroscience connect to

other parts of life science, physics, and mathematics? Lectures and guided reading will touch on a broad range of phenomena from evolution, development, biophysics, computation, behavior, and psychology. Students will benefit from prior exposure to at least some of these domains. Given in alternate years; not offered 2025-26. Instructor: Meister.

NB/Bi/BE 155. Neuropharmacology. *6 units (3-0-3); second term. Prerequisites: NB/Bi/CNS 150.* The neuroscience of drugs for therapy, for prevention, and for recreation. Students learn the prospects for new generations of medications in neurology, psychiatry, aging, and treatment of substance abuse. Topics: Types of drug molecules, Drug receptors, Electrophysiology, Drugs activate ion channels, Drugs block ion channels, Drugs activate and block G protein pathways, Drugs block neurotransmitter transporters, Pharmacokinetics, Recreational drugs, Nicotine Addiction, Opiate Addiction, Drugs for neurodegenerative diseases: Alzheimer's disease, Parkinson's disease, Drugs for epilepsy and migraine, and Psychiatric diseases: Nosology and drugs. The course is taught at the research level. Given in alternate years; not offered 2025-26. Instructor: Lester.

NB/Bi/CNS 162. Cellular and Systems Neuroscience Laboratory. *12 units (2-4-6); first term. Prerequisites: NB/Bi/CNS 150 or instructor's permission.* A laboratory-based introduction to experimental methods used for electrophysiological studies of the central nervous system. Through the term, students investigate the physiological response properties of neurons in vertebrate and invertebrate brains, using extra- and intracellular recording techniques. Students are instructed in all aspects of experimental procedures, including proper surgical techniques, electrode fabrication, and data analysis. The class also includes a brain dissection and independent student projects that utilize modern digital neuroscience resources. Instructors: Oka, Wagenaar.

NB/Bi/CNS 163. The Biological Basis of Neural Disorders. *6 units (3-0-3); second term. Prerequisites: NB/Bi/CNS 150 or instructor's permission.* The neuroscience of psychiatric, neurological, and neurodegenerative disorders and of substance abuse, in humans and in animal models. Students master the biological principles including genetics, cell biology, biochemistry, physiology, and circuits. Topics are taught at the research level and include classical and emerging therapeutic approaches and diagnostic strategies. Given in alternate years; offered 2025-26. Instructors: Lester, Lois.

NB/Bi/CNS 164. Tools of Neurobiology. *9 units (3-0-6); first term. Prerequisites: NB/Bi/CNS 150 or equivalent.* Offers a broad survey of methods and approaches to understanding in modern neurobiology. The focus is on understanding the tools of the discipline, and their use will be illustrated with current research results. Topics include: molecular genetics, disease models, transgenic and knock-in technology, virus tools, tracing methods, gene profiling, light and electron microscopy, optogenetics, optical and electrical recording, neural coding, quantitative

behavior, modeling and theory. Instructor: Meister.

Pl/CNS/NB/Bi/Psy 167. Consciousness. *9 units (3-0-6);* For course description, see Philosophy

CNS/Bi/Psy/NB 176. Cognition. *9 units (4-0-5);* For course description, see Computation & Neural Systems

CNS/Bi/EE/CS/NB 186. Vision: From Computational Theory to Neuronal Mechanisms. *12 units (4-4-4);* For course description, see Computation & Neural Systems

CNS/Bi/Ph/CS/NB 187. Neural Computation. *9 units (3-0-6);* For course description, see Computation & Neural Systems

Bi/CNS/NB 195. Mathematics in Biology. *9 units (3-0-6);* For course description, see Biology

BE/Bi/CNS/NB 197. Mentoring and Outreach. *Units to be arranged, up to 12 units per year;* For course description, see Bioengineering

BE/Bi/NB 203. Introduction to Programming for the Biological Sciences Bootcamp. *6 units;* For course description, see Bioengineering

NB/Bi/CNS 216. Behavior of Mammals. *6 units (2-0-4); first term.* A course of lectures, readings, and discussions focused on the genetic, physiological, and ecological bases of behavior in mammals. A basic knowledge of neuroanatomy and neurophysiology is desirable. Given in alternate years. Offered 2025-26. Instructor: Allman.

NB/Bi/CNS 220. Genetic Dissection of Neural Circuit Function. *6 units (2-0-4); third term. Prerequisites: NB/Bi/CNS 150 or equivalent. Open to advanced (junior or senior) undergraduates only and with instructor permission.* This advanced course will discuss the emerging science of neural "circuit breaking" through the application of molecular genetic tools. These include optogenetic and pharmacogenetic manipulations of neuronal activity, genetically based tracing of neuronal connectivity, and genetically based indicators of neuronal activity. Both viral and transgenic approaches will be covered, and examples will be drawn from both the invertebrate and vertebrate literature. Interested CNS or other graduate students who have little or no familiarity with molecular biology will be supplied with the necessary background information. Lectures and student presentations from the current literature. Instructor: Anderson.

Bi/CNS/BE/NB 230. Optogenetic and CLARITY Methods in Experimental Neuroscience. *9 units (3-2-4);* For course description, see Biology

Bi/BE/CNS/NB 241. Spatial Genomics. *9 units (1-8-0);* For course description, see Biology

CNS/Bi/NB 247. Cerebral Cortex. *6 units (2-0-4);* For course description, see Computation & Neural Systems

NB/Bi/CNS 250 c. Topics in Systems Neuroscience. *9 units (3-0-6); third term. Prerequisites: graduate standing.* The class focuses on quantitative studies of problems in systems neuroscience. Students will study classical work such as Hodgkin and Huxley's landmark papers on the ionic basis of the action potential, and will move from the study of interacting currents within neurons to the study of systems of interacting neurons. Topics will include lateral inhibition, mechanisms of motion tuning, local learning rules and their consequences for network structure and dynamics, oscillatory dynamics and synchronization across brain circuits, and formation and computational properties of topographic neural maps. The course will combine lectures and discussions, in which students and faculty will examine papers on systems neuroscience, usually combining experimental and theoretical/modeling components. Instructor: Siapas.

CNS/Bi/NB 256. Brain-machine interfaces. *6 units (2-0-4);* For course description, see Computation & Neural Systems

NB 299. Graduate Research. *Units to be arranged; first, second, third terms.* Students may register for research units after consultation with their adviser.

PERFORMING AND VISUAL ARTS

PVA 30 abc. Guitar. *3 units (0-3-0); first, second, third terms.* Offered on three levels: beginning (no previous experience required), intermediate, and advanced. Instruction emphasizes a strong classical technique, including an exploration of various styles of guitar-classical, flamenco, folk, and popular. Instructor: Elgart.

PVA 31 abc. Chamber Music. *3 units (0-3-0); first, second, third terms.* Study and performance of music for instrumental ensembles of two to eight members, and for piano four-hands. Literature ranges from the 16th to the 21st centuries. Open to students who play string, woodwind, and brass instruments; guitar; or piano. Pianists will be placed in sections by the instructors following their auditions. Coachings occur weekly for one hour. Section 1: Mixed ensembles. Section 2: Piano four-hands. Section 3: Guitar ensemble. Instructors: Jasper White, Ward, Chalifour, Elgart, Park.

PVA 32 abc. Symphony Orchestra. *3 units (0-3-0); first, second, third terms.* Study and performance of music written for full symphony orchestra and chamber orchestra. The orchestra performs both the standard symphonic repertoire and contemporary music. Two and a half hours of rehearsal per week. Instructor: Price.

PVA 33 abc. Wind Orchestra. *3 units (0-3-0); first, second, third terms.* The Caltech Wind Orchestra is comprised of students, faculty, staff, and alumni. The ensemble rehearses Thursday nights from 7:30-9:45 pm. and performs three programs per year (one per term) at Ramo Auditorium and other Los Angeles venues. Repertoire consists of traditional and contemporary music encompassing a wide variety of styles, and regularly features renowned guest artists. Open to students of all levels of previous experience. Instructor: Price.

PVA 34 abc. Jazz Band/Jazz Improvisation. *3 units (0-3-0); first, second, third terms.* Comprised of students, faculty, staff, JPL, alumni, and community members by audition. The jazz band performs a diverse range of big-band jazz styles, from Duke Ellington to Maria Schneider, with performances held three times a year, often featuring legendary jazz musicians. The Jazz Improv class studies the process of improvisation, performs regularly, and is open to all levels of experience. Instructor: Catlin.

PVA 35 abc. Glee Club. *3 units (0-3-0); first, second, third terms.* Preparation and performance of choral repertoire spanning a range of historical periods and musical styles. Includes occasional collaborative performances with the orchestra. No previous experience required. Three hours a week. Instructor: Sulahian.

PVA 37 abc. Chamber Singers. *3 units (0-3-0); first, second, third terms.* Advanced study and performance of SATB choral music. Emphasis is placed on more difficult choral repertoire, both a capella and accompanied. Includes performances with the Glee Clubs as well as at other on-campus events. Audition required. Participation in Glee Clubs required. Instructor: Sulahian.

PVA 40 abc. Theater Arts Production. *3 units (2-0-1); first, second, third terms.* Instruction in all phases of theatrical production, culminating in multiple performances for the public with a hands-on, practical approach including stage combat, costume construction, scenic arts, lighting, sound, and mentorship with professional actors, designers, and directors. Material of academic value is drawn from 3,000 years of worldwide dramatic literature. Problem solving, collaborative team building with an understanding of dramatic structure is stressed. Instructor: Brophy.

PVA 41 abc. Storytelling for Scientists. *3 units (2-0-1); first, second, third terms.* Across three terms students explore/write and perform new narratives for the ever-changing 21st century global landscape. 41 a includes finding your stories. Moth to the Flame 41 b builds complex social/scientific narratives, and practices citizen science and democracy in open forums. 41 c concludes with long-form storytelling. All final classes culminate in original stories recorded in front of a live audience. May be repeated for credit. Instructor: Brophy.

PVA 42 abc. Improvisation for Scientists. *3 units (2-0-1); first, second, third terms.* This class is taught sequentially over the academic year and begins with rudimentary improvisation and continues in the winter/spring with professional improvisation guidance, long form improvisation, musical improv, and advanced techniques with public performances. Instructor: Brophy.

PVA 61 abc. Silk Painting. *3 units (0-3-0); first, second, third terms.* Progressive development of silk painting skills for fine art. Option to pursue watercolors as well. Emphasis on student-chosen subjects with a large reference library. Instructor: Barry.

PVA 62 abc. Drawing and Painting. *3 units (0-3-0); first, second, third terms.* Instruction in painting techniques in acrylics, watercolor, and life drawing of models. Emphasis on student-chosen subjects with a large reference library. Instructor: Barry.

PVA 63 abc. Ceramics. *3 units (0-3-0); first, second, third terms.* Instruction in the techniques of creating ceramics, including the slab roller and potter's wheel, and glazing methods. Instructor: Plunkett.

PHILOSOPHY

Hum/Pl 40. Right and Wrong. *9 units (3-0-6);* For course description, see Humanities

Hum/Pl 41. Knowledge and Reality. *9 units (3-0-6);* For course description, see Humanities

Hum/Pl 44. Philosophy Through Science Fiction. *9 units (3-0-6);* For course description, see Humanities

Hum/Pl 45. Ethics & AI. *9 units (3-0-6);* For course description, see Humanities

Hum/Pl 58. Special Topics in Humanities/Philosophy. *Units are by arrangement;* For course description, see Humanities

Pl 89. Applied Ethics (Ethics Bowl). *3 units (3-0-0); first term.* This course will prepare a team to participate in the regional Intercollegiate Ethics Bowl in November/December. The Ethics Bowl provides students with the opportunity to discuss and work towards solving complex ethical issues in a team setting. The course will be structured around the ~15 case studies we receive, and consist of learning argumentative tools in moral philosophy, researching and analyzing the case studies, and debate practice in the lead-up to the tournament. During the tournament we will present & defend our analyses and engage with the analyses of other teams. Cases range from various practical contexts, including science & engineering, medicine, education, public policy, and personal

life. If successful in the regional competition, our team will be invited to the National competition (Feb-March) which involves a new set of cases. The class will meet once a week (3 hours). Attendance to the tournament is required and travel expenses will be covered. Not offered 2025-26. .

Pl 90 ab. Senior Thesis. *9 units (1-0-8);* Required of students taking the philosophy option. To be taken in any two consecutive terms of the senior year. Students will research and write a thesis of 10,000-12,000 words on a philosophical topic to be determined in consultation with their thesis adviser. Limited to students taking the philosophy option. Instructor: Staff.

Pl 98. Reading in Philosophy. *9 units (1-0-8); Prerequisites: instructor's permission.* An individual program of directed reading in philosophy, in areas not covered by regular courses. Instructor: Staff.

Pl/Law 99. Causation and Responsibility. *9 units (3-0-6); third term.* This course will examine the interrelationships between the concepts of causation, moral responsibility, and legal liability. It will consider legal doctrines of causation and responsibility, as well as attempts within philosophy to articulate these concepts. Questions to be addressed include: Can you be morally or legally responsible for harms that you do not cause? Is it worse to cause some harm, than to unsuccessfully attempt it? Is it justified to punish those who cause harm more severely than those who attempt harm? When, if ever, can the ends justify the means? What constitutes negligence? Is it worse to cause some harm, than to allow it to happen (when you could have prevented it)? Not offered 2025-26.

Pl 100. Free Will. *9 units (3-0-6); third term.* This course examines the question of what it means to have free will, whether and why free will is desirable, and whether humans have free will. Topics may include historical discussions of free will from writers such as Aristotle, Boethius, and Hume; what it means for a scientific theory to be deterministic, and whether determinism is compatible with free will; the connection between free will and moral responsibility; the relationship between free will and the notion of the self; beliefs about free will; the psychology of decision making; and the insanity defense in law. Not offered 2025-26.

Pl 102. Selected Topics in Philosophy. *9 units (3-0-6); Offered by announcement. Prerequisites: Hum/Pl 40 or Hum/Pl 41 or instructor's permission.*

HPS/Pl/CS 110. Causation and Explanation. *9 units (3-0-6);* For course description, see History and Philosophy of Science

HPS/Pl 120. Introduction to Philosophy of Science. *9 units (3-0-6);* For course description, see History and Philosophy of Science

HPS/Pl 122. Probability, Evidence, and Belief. *9 units (3-0-6);* For course description, see History and Philosophy of Science

HPS/Pl 123. Introduction to the Philosophy of Physics. *9 units (3-0-6);* For course description, see History and Philosophy of Science

HPS/Pl 124. Philosophy of Space and Time. *9 units (3-0-6);* For course description, see History and Philosophy of Science

HPS/Pl 125. Philosophical Issues in Quantum Physics. *9 units (3-0-6);* For course description, see History and Philosophy of Science

HPS/Pl 128. Philosophy of Mathematics. *9 units (3-0-6);* For course description, see History and Philosophy of Science

HPS/Pl 136. Happiness and the Good Life. *9 units (3-0-6);* For course description, see History and Philosophy of Science

HPS/Pl 138. Human Nature and Society. *9 units (3-0-6);* For course description, see History and Philosophy of Science

HPS/Pl 139. Human Nature, Welfare, & Sustainability. *9 units (3-0-6);* For course description, see History and Philosophy of Science

HPS/Pl 165. Selected Topics in Philosophy of Science. *9 units (3-0-6);* For course description, see History and Philosophy of Science

Pl/CNS/NB/Bi/Psy 167. Consciousness. *9 units (3-0-6); third term. Prerequisites: None, but strongly suggest prior background in philosophy of mind and basic neurobiology (such as Bi 150).* One of the last great challenges to our understanding of the world concerns conscious experience. What exactly is it? How is it caused or constituted? And how does it connect with the rest of our science? This course will cover philosophy of mind, cognitive psychology, and cognitive neuroscience in a mixture of lectures and in-class discussion. There are no formal pre-requisites, but background in philosophy (equivalent to Pl 41, Pl 110) and in neuroscience (equivalent to NB/Bi/CNS 150) is strongly recommended and students with such background will be preferentially considered. Limited to 20. Instructor: Adolphs/Eberhardt.

Pl/HPS 183. Bioethics. *9 units (3-0-6); third term.* A survey of issues in bioethics. Topics may include: abortion and reproductive rights; euthanasia; physician-patient relationships; use of human embryos and stem cells in research; use of human subjects in research and the concept of informed consent; research on and treatment of non-human animals; organ transplantation, distribution, and sale; genetic modification of organisms (including humans); synthetic biology; cure vs. enhancement and other issues in biotechnology and neuroethics. Instructor: Helou.

Pl 185. Moral Philosophy. *9 units (3-0-6); second term.* A survey of topics in moral philosophy. The emphasis will be on metaethical issues, although some normative questions may be addressed. Metaethical

topics that may be covered include the fact/value distinction; the nature of right and wrong (consequentialism, deontological theories, rights-based ethical theories, virtue ethics); the status of moral judgments (cognitivism vs. noncognitivism, realism vs. irrealism); morality and psychology; moral relativism; moral skepticism; morality and self-interest; the nature of justice. The implications of these theories for various practical moral problems may also be considered. Not offered 2025-26.

PHYSICAL EDUCATION

PE 1. Wellness. *3 units; offered by announcement.* An introductory survey course of important topics of physical, mental and overall health and wellness for students designed to be taken in the first two years. Topics include basic principles and components of exercise and physical conditioning, the role of sleep and nutrition in overall health, time and stress management skills, emotional and mental self and community care principals. The course will be team taught by members of the physical education department in collaboration with other student affairs partners and resources. Instructor: Staff.

PE 2. Student Designed Fitness. *3 units; offered by announcement.* This course provides students with knowledge and practical opportunities to develop and implement an individualized program to successfully accomplish their physical fitness goals. Detailed proposals are developed during week two of the term, and journals are maintained throughout the term to monitor progress. *May only be used for 3 units of the 9-unit physical education requirement.*. Instructor: Staff.

PE 3. Hiking. *3 units; offered by announcement.* This course is designed to provide students an opportunity to explore the outdoors of Pasadena and the San Gabriel Mountains while participating in physical fitness activities. Learn about proper hiking gear, basics for safety, trip plans, and how to research trails in the local area. The class will meet on campus and then travel to one of the local trails for an afternoon hike. Students will be asked to use maps, compass, and GPS devices on various hikes to teach them proper use of all forms of location guidance. Along the trail, students will be asked to identify local flora and vegetation, learn trail etiquette, discuss survival scenarios in the event of emergency, and practice basic trail first aid. Topics such as trail nutrition and hydration will be presented, and students will create a search and rescue plans in the event of an overnight emergency. This class will only be offered on Friday morning, meeting once per week for a three-hour block to accommodate travel off campus. Instructor: Staff.

PE 4. Introduction to Power Walking. *3 units; offered by announcement.* Introduction to walking for fitness. Emphasis on cardiovascular benefits for a healthy lifestyle. The program is progressive and suitable for walkers of all levels. Instructor: Staff.

PE 5. Beginning Running. *3 units; offered by announcement.* Students will learn fundamental principles of sound running training to help with short-term and long-term improvement. The course will cover workout design, running mechanics, injury prevention and other related topics. The course can accommodate a wide range of abilities and experience levels, from beginner to intermediate. Course assessments will include fitness tests to gauge improvement and written work on running-related topics. Instructor: Staff.

PE 6. Core Training, Beginning/Intermediate. *3 units; offered by announcement.* Learn to develop functional fitness using core stability training techniques that focus on working deep muscles of the entire torso at once. The course is taught using exercises that develop core strength, including exercises on a stability ball, medicine ball, wobble boards as well as with Pilates exercise programs. Instructor: Staff.

PE 7. Speed and Agility Training, Beginning/Intermediate. *3 units; offered by announcement.* Instruction to increase foot speed and agility with targeted exercises designed to help the student increase these areas for use in competitive situations. Instruction will focus on increasing foot speed, leg turnover, sprint endurance, and competitive balance. Proper technique and specific exercises as well as development of an individual or sport-specific training workout will be taught. Instructor: Staff.

PE 8. Pickleball, Beginning. *3 units; offered by announcement.* An introductory course for students who are new to Pickleball. Fundamentals of the game will be emphasized, including rules, scoring, strategy, and winning shots. The course will emphasize groundstrokes, volleys, serve, and grips. Singles and doubles games will be played. Instructor: Staff.

PE 9. Soccer. *3 units; offered by announcement.* Fundamental instruction on shooting, passing, trapping, dribbling, penalty kicks, offensive plays, defensive strategies, and goal keeping. Course includes competitive play using small field and full field scrimmages. Instructor: Staff.

PE 10. Aerobic Dance. *3 units; offered by announcement.* Each class includes a thorough warm-up, a cardiovascular workout phase that includes a variety of conditioning exercises designed to tone and strengthen various muscle groups, and a relaxation cool-down and stretch, all done to music. Instructor: Staff.

PE 14. Basketball Skills, Beginning and Intermediate. *3 units; offered by announcement.* Features fundamental instruction on shooting, dribbling, passing, defensive positioning, and running an offense. Course includes competitive play and free-throw shooting. Instructor: Staff.

PE 20. Fencing, Beginning. *3 units; offered by announcement.* Beginning fencing includes basic techniques of attack, defense, and counter-offense. Lecture topics include fencing history, strategy, scouting and analysis of opponents, and gamesmanship. Instructor: Staff.

PE 22. Stretching. *1 unit; offered by announcement.* Loosen up, stretch out, and practice relaxation techniques. The practice of stretching and building flexibility is integral to personal health and wellness. Whether training for a sport or recovering from sedentary work (classes, homework, sitting in a lab), stretching can prevent injury, improve range of motion, increase blood flow, boost energy, help to correct imbalances in the body, and aid in recovery. Each class will consist of a brief warm up, followed by guided stretches focused on various muscle groups and areas of the body, and will conclude with individual written reflections in a stretching log to track progress and development throughout the course. Upon completion of this course, students will be able to safely and independently incorporate their own stretching routines into their daily lives. Instructor: Staff.

PE 23. Pilates. *3 units; offered by announcement.* Pilates is a body conditioning technique designed to stretch, strengthen and balance the body. Pilates targets the deep postural muscles within the body through a series of exercises aimed at building muscle strength and rebalancing the body. Students will focus on developing core strength, joint flexibility and body awareness by engaging in a variety of exercises that integrate the principles of Pilates (concentration, control, center, flow, precision and breathing). This class will utilize class instruction, assignments and student participation to enable students to: 1. Acquire knowledge of the basic health related components of physical fitness and the different dimension of wellness. 2. Develop the skill related components of fitness, and 3. Understand and practice the behaviors that contribute to a healthy lifestyle. Instructor: Staff.

PE 24. Yoga, Beginning. *3 units; offered by announcement.* Hatha Yoga is a system of physical postures designed to stretch and strengthen the body, calm the nervous system, and center the mind. It is a noncompetitive activity designed to reduce stress for improved health of body and mind while increasing flexibility, strength, and stamina, and reducing chance of athletic injury. Instructor: Staff.

PE 25. Meditation. *1 unit; offered by announcement.* Meditation is a technique for making the mind more stable, peaceful and clear and for developing insight and good qualities. This course is designed to help you find a way to meditate by covering a variety of meditation techniques, including mindfulness, body scans, guided imagery, walking and breathing techniques. Learn simple practices to help you focus more, stress less, and increase self-compassion in a supportive environment. Fitness and movement principles will be taught to train the mind and body.

PE 27. Ultimate Frisbee. *3 units; offered by announcement.* This course will center on developing students' knowledge of techniques, rules, strategy, etiquette, and safety regulations of the game. Students will develop the ability to perform all the skills necessary to play ultimate Frisbee confidently on a recreational basis. Instructor: Staff.

PE 29. Outdoor Lawn Games. *3 units; offered by announcement.* Students will participate in 5 specifically chosen strategic games (Inner Tube Water Polo, Dodgeball, Bocce, Corn Hole, Flag Football, Pickleball) and learn basic strategy and rules, fitness and health components as well as learning how to compete in cooperative team games. Course requirements include great attitude, attendance and effort of having fun and trying something new while working on your coordination and general fitness. Instructor: Staff.

PE 30. Golf, Beginning and Intermediate. *3 units; offered by announcement.* Beginning course covers fundamentals of the game, including rules, terminology, etiquette, basic grip, set-up, swing, and club selection for each shot. The following shots will be covered: full swing (irons and woods), chip, pitch, sand, and putting. Intermediate course will focus on swing development of specialty shots and on course play management. Instructor: Staff.

PE 31. Indoor Cycling. *3 units; offered by announcement.* During this introductory course students will utilize indoor cycling as a tool for fitness and fun. This course is designed to teach students basic concepts associated with indoor cycling as well as build cardio-respiratory endurance, muscular strength, and flexibility through structured indoor cycling workouts. Students will also learn and apply principles of lifetime physical fitness. Instructor: Staff.

PE 33. Beginning Triathlon Training. *3 units; offered by announcement.* This course is designed to help beginners learn to train for a sprint distance triathlon. All three disciplines will be taught, with specific technique instruction in each area. Students will learn how to develop a training schedule, choosing the correct event for their skill, nutrition, safety, and race preparation. The course will include techniques to increase transition efficiency, trouble shoot issues on the route and strategies to record a personal best in future races. Safe training to reduce injury and assure a healthy race is the foundation of this course. Instructor: Staff.

PE 35. Diving, Beginning/Intermediate. *3 units; offered by announcement.* Students will learn fundamentals of springboard diving to include basic approach, and five standard dives. Intermediate course includes instruction in the back somersault, forward somersault, forward somersault full twist, and reverse somersault. Instructor: Staff.

PE 36. Swimming, Beginning and Intermediate. *3 units; offered by announcement.* Instruction in all basic swimming strokes, including freestyle, elementary backstroke, racing backstroke, breaststroke,

sidestroke, and butterfly. Instructor: Staff.

PE 38. Water Polo. *3 units; offered by announcement.* Basic recreational water polo with instruction of individual skills and team strategies. A background in swimming is encouraged. Instructor: Staff.

PE 40. Beginning Self Defense. *1 unit; offered by announcement.* Students will learn basics of keeping themselves safe when an unknown person threatens their safety. The course is focused on staying safe while rendering an assailant temporarily unable to give chase to allow the student to get help. Techniques taught will assist students in learning vulnerable targets to disable an attacker, using their own body to maximize damage to allow escape, and finding methods to generate force. Using an assailant's attack against him to maintain balance and administer the greatest degree of force necessary to disable a threat is the foundation of the course. Instructor: Staff.

PE 44. Karate (Shotokan), Beginning and Intermediate/Advanced. *3 units; offered by announcement.* Fundamental self-defense techniques including form practice and realistic sparring. Emphasis on improving muscle tone, stamina, balance, and coordination, with the additional requirement of memorizing one or more simple kata (forms). Instructor: Staff.

PE 48. T'ai-Chi Ch'uan, Beginning and Intermediate. *3 units; offered by announcement.* Chinese movement art emphasizing relaxation and calm awareness through slow, flowing, meditative movement using only minimum strength needed to accomplish the action. Instructor: Staff.

PE 50. Badminton, Beginning/Intermediate. *3 units; offered by announcement.* Basic skills will be taught, including grips, services, overhead and underhand strokes, and footwork. Rules, terminology, and etiquette are covered. Intermediate skills such as drives, serve returns, forehand and backhand smash returns, attacking clears, and sliced drop shots are taught. Singles and doubles play along with drill work throughout the term. Instructor: Staff.

PE 54. Racquetball, Beginning and Intermediate. *3 units; offered by announcement.* Fundamentals of the game will be emphasized, including rules, scoring, strategy, and winning shots. All types of serves will be covered, as well as a variety of shots to include kill, pinch-off, passing, ceiling, and off-the-backwall. Singles and doubles games will be played. Intermediate course will review all fundamentals with a refinement of winning shots, serves, and daily games. Instructor: Staff.

PE 56. Squash, Beginning, Intermediate, Advanced. *3 units; offered by announcement.* Learn by playing as basic rules and strokes are taught. Fundamentals to include proper grip, stroke, stance, and positioning, along with serve and return of serve. Intermediate and Advanced course will concentrate on skill development with inclusion of forehand and backhand drives, lobs, volleys, and drops, with emphasis on court

movement, shot selection, and tactics. Instructor: Staff.

PE 60. Tennis, Beginning and Intermediate. *3 units; offered by announcement.* Stroke fundamentals, singles and doubles play, plus rules, terminology, and etiquette are covered in all classes. Beginning course emphasizes groundstrokes, volleys, serve, and grips. Beginning/Intermediate course is for those players between levels and will concentrate on strategy, drills, and match play. Intermediate level focuses on improving technique, footwork, and court positioning, with instruction on approach shots, volleys, overheads, and lobs. Instructor: Staff.

PE 70. Weight Training, Beginning. *3 units; offered by announcement.* Active participation in a strength and conditioning program designed for individual skill level and desired effect. Course will enlighten students on various methods, terminology, and techniques in isokinetic strength and cardiovascular fitness training. Instructor: Staff.

PE 71. Weight Training, Intermediate. *3 units; offered by announcement. Prerequisites: PE 70, instructor approval.* This course is intended for those experienced with high level physical training. This course helps individuals improve sport and physical fitness skills by addressing components including muscular strength, cardiovascular conditioning and flexibility. Active participation in a strength and conditioning program designed for individual skill level and desired effect. Instructor: Staff.

PE 77. Volleyball, Beginning and Intermediate. *3 units; offered by announcement.* Fundamental instruction on drills, strategies, and rules, with game-playing opportunities. Basics of serve, pass, set, spike, defense, and court position will be taught. Intermediate level focuses on skill development to a more competitive standard and features multiple offenses and understanding officiating. Instructor: Staff.

PE 81. Bouldering. *3 units; offered by announcement.* Taught at the Caltech bouldering cave, Brown Gym. During this introductory course to bouldering, students will learn terminology, how to properly fit into a harness, set-up and use a tubular belay device, and belay commands. This course will emphasize muscle strength and endurance, balance, and flexibility, as well as be challenging for mind and body. Instructor: Staff.

PE 82. Rock Climbing, Beginning/Intermediate. *3 units; offered by announcement.* Taught at the Caltech Climbing Wall, Brown Gym. Basic skills will be covered to utilize each student's strength and endurance while learning to climb safely. Use of climbing rope and other equipment for belaying, rappelling, and emergency ascent will be taught. Instructor: Staff.

PE 84. Table Tennis, Beginning/Intermediate. *3 units; offered by announcement.* Introductory course to provide general knowledge of

equipment, rules, and basic strokes, including topspin drive, backspin chop, and simple block in both forehand and backhand. Multiball exercise utilizing robot machines and video. Intermediate class covers regulations for international competition and fundamentals of winning table tennis, including footwork drills, smash, serve, and attack. Instructor: Staff.

PE 85. Intercollegiate Track and Field Teams. *3 units; second, third terms.* Intercollegiate Track and Field Teams for units. Instructor: Blake.

PE 87. Intercollegiate Swimming and Diving Teams. *3 units; first, second terms.* Intercollegiate Swimming and Diving Teams for units. Instructor: Brabson.

PE 90. Intercollegiate Water Polo Teams. *3 units; first, second, third terms.* Intercollegiate Water Polo Teams for units. Instructor: Bonafede.

PE 91. Intercollegiate Basketball Teams. *3 units; first, second terms.* Intercollegiate Basketball Teams for units. Instructors: Eslinger, Tarakchian.

PE 92. Intercollegiate Soccer Teams. *3 units; first term.* Intercollegiate Soccer Teams for units. Instructors: Gillis, Gould.

PE 93. Intercollegiate Baseball Team. *3 units; second, third terms.* Intercollegiate Baseball Team for units. Instructor: Whitehead.

PE 95. Intercollegiate Tennis Teams. *3 units; second, third terms.* Intercollegiate Tennis Teams for units. Instructors: Brisotti, Weintraub.

PE 97. Intercollegiate Cross-Country Teams. *3 units; first term.* Intercollegiate Cross-Country Teams for units. Instructor: Blake.

PE 99. Intercollegiate Volleyball Team. *3 units; first term.* Intercollegiate Volleyball Team for units. Instructor: Gardner.

PHYSICS

IC/Ph 1 abc. Integrated Core: Classical Mechanics and Electromagnetism. *9 units (3-1-5);* For course description, see Integrated Core

Ph 1 abc. Classical Mechanics and Electromagnetism. *9 units (4-0-5); first, second, third terms.* A year-long introductory course on classical physics. Topics: Newtonian mechanics in Ph 1 a; electricity and magnetism, and special relativity, in Ph 1 b, c. Emphasis on physical insight and problem solving. Ph 1 b, c is divided into two tracks: the Practical Track emphasizes order-of-magnitude estimations; the Analytic Track teaches and uses methods of multivariable calculus. Students

enrolled in the Practical Track are encouraged to take Ph 8 bc concurrently. Students will be given information helping them to choose a track at the end of fall term. Instructors: Ravi, Patterson, X. Chen.

Ph 2 abc. Waves, Quantum Mechanics, and Statistical Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 1 abc, Ma 1 abc.* An introduction to several areas of physics including applications in modern science and engineering. Topics include discrete and continuous oscillatory systems, wave mechanics, applications in telecommunications and other areas (first term); foundational quantum concepts, the quantum harmonic oscillator, the Hydrogen atom, applications in optical and semiconductor systems (second term); heat engines, thermodynamic laws, statistical systems and their relationship with the arrow of time, including applications in energy technology and other areas. There will be an optional demo lab participation (third term). Although best taken in sequence, the three terms can be taken independently. Instructors: McCuller, Filippone, Hildebrandt.

Ph 3. Introductory Physics Laboratory. *6 units (0-3-3); first, second, third terms. Prerequisites: Ph 1 a or instructor's permission.* Introduction to experimental physics and data analysis, with techniques relevant to all fields that deal in quantitative data. Specific physics topics include ion trapping, harmonic motion, mechanical resonance, and precision interferometry. Broader skills covered include introductions to essential electronic equipment used in modern research labs, basic digital data acquisition and analysis, statistical interpretation of quantitative data, professional record keeping and documentation of experimental research, and an introduction to the Mathematica programming language. Only one term may be taken for credit. Instructors: Black, Libbrecht.

FS/Ph 4. First-Year Seminar: Astrophysics and Cosmology with Open Data. *6 units (2-0-4);* For course description, see First-Year Seminars

Ph 5. Analog Electronics for Physicists. *9 units (0-5-4); first term. Prerequisites: Ph 1 abc, Ma 1 abc, Ma 2 taken concurrently.* A fast-paced laboratory course covering the design, construction, and testing of practical analog and interface circuits, with emphasis on applications of operational amplifiers. No prior experience with electronics is required. Basic linear and nonlinear elements and circuits are studied, including amplifiers, filters, oscillators and other signal conditioning circuits. Each week includes a 45 minute lecture/recitation and a 2½ hour laboratory. The course culminates in a two-week project of the student's choosing. Instructors: Rice, Libbrecht.

Ph 6. Physics Laboratory. *9 units; second term. Prerequisites: Ph 2 a or Ph 12 a, Ma 2, Ph 3, Ph 2 b or Ph 12 b (may be taken concurrently), Ma 3 (may be taken concurrently).* A laboratory introduction to experimental physics and data analysis. Experiments use research-grade equipment and techniques to investigate topics in classical electrodynamics, resonance phenomena, waves, and other physical phenomena. Students

develop critical, quantitative evaluations of the relevant physical theories; they work individually and choose which experiments to conduct. Each week includes a 30-minute individual recitation and a 3 hour laboratory. Instructors: Rice, Politzer.

Ph 7. Physics Laboratory. *9 units; third term. Prerequisites: Ph 6, Ph 2 b or Ph 12 b, Ph 2 c or Ph 12 c taken concurrently.* A laboratory course continuing the study of experimental physics introduced in Physics 6. The course introduces some of the equipment and techniques used in quantum, condensed matter, nuclear, and particle physics. The menu of experiments includes some classics which informed the development of the modern quantum theory, including electron diffraction, the Stern-Gerlach experiment, Compton scattering, and the Mössbauer Effect. The course format follows that of Physics 6: students work individually and choose which experiments to conduct, and each week includes a 30 minute individual recitation and a 3 hour laboratory. Instructors: Rice, Politzer.

Ph 8 bc. Experiments in Electromagnetism. *3 units (0-3-0); second, third terms. Prerequisites: Ph 1 a.* A two-term sequence of experiments that parallel the material of Ph 1 bc. It includes measuring the force between wires with a homemade analytical balance, measuring properties of a 1,000-volt spark, and building and studying a radio-wave transmitter and receiver. The take-home experiments are constructed from a kit of tools and electronic parts. Measurements are compared to theoretical expectations. Instructor: Spiropulu.

FS/Ph 9. The Science of Music. *6 units (2-0-4);* For course description, see First-Year Seminars

Ph 10. Frontiers in Physics. *3 units (2-0-1); first term.* Open for credit to first-year students and sophomores. Weekly seminar by a member of the physics department or a visitor, to discuss their research at an introductory level; the other class meetings will be used to explore background material related to seminar topics and to answer questions that arise. The course will also help students find faculty sponsors for individual research projects. Graded pass/fail. Instructor: Spiropulu.

FS/Ph 11 abc. First-Year Seminar: Beyond Physics. *6 units (2-0-4);* For course description, see First-Year Seminars

Ph 12 abc. Waves, Quantum Physics, and Statistical Mechanics. *9 units (4-0-5); first, second, third terms. Prerequisites: Ph 1 abc, Ma 1 abc, or equivalents.* A one-year course primarily for students intending further work in the physics option. Topics include classical waves; wave mechanics, interpretation of the quantum wave-function, one-dimensional bound states, scattering, and tunneling; thermodynamics, introductory kinetic theory, and quantum statistics. Instructors: Zmuidzinas, Golwala.

FS/Ph 15. First-Year Seminar: Quantum Information Science Today and Tomorrow. *6 units (2-0-4);* For course description, see First-Year Seminars

Ph 20. Computational Physics Laboratory I. *6 units (0-6-0); first term. Prerequisites: CS 1 or equivalent.* The course introduces numerical methods and scientific programming for solving physics using Python. Topics include numerical integration, root finding, linear systems, and differential equations, all within the context of physical models. Emphasis is placed on developing reliable, readable code and interpreting numerical output in terms of physical behavior. Students are expected to already be familiar with working in a UNIX environment. This includes navigating directories, using the command line, managing Python virtual environments, and employing version control systems. These tools will be used throughout the course but will not be taught explicitly. Students must be able to install packages, execute scripts, and track code changes as part of their regular workflow. Instructor: Adhikari.

Ph 21. Computational Physics Laboratory II. *6 units (0-6-0); second term. Prerequisites: Ph 20.* This course covers computational techniques for signal processing and weak signal detection in physics. Topics include Fourier transforms, filtering, power spectral density estimation, matched filtering, and introductory Bayesian methods. Students will develop tools to extract signals from noisy data and quantify the confidence of detection. Applications are drawn from gravitational wave detection, high-energy physics experiments, and quantum hypothesis testing. Emphasis is placed on practical data analysis and the construction of reliable, well-documented analysis pipelines for real or simulated datasets. Instructor: Adhikari.

Ph 22. Computational Physics Laboratory III. *6 units (0-6-0); third term. Prerequisites: Ph 20 + Ph 21.* An introduction to machine learning techniques for modeling and analyzing physical systems. Topics include classification, regression, dimensionality reduction, and the construction of simple neural networks. Students will apply these methods to datasets from physics experiments and simulations, using machine learning to identify patterns, build predictive models, and work with high-dimensional data. The course also includes one reinforcement learning problem, focused on optimizing control in a basic physical system. Emphasis is placed on understanding when and how to apply ML techniques in physics, with attention to interpretability, overfitting, and the use of physical constraints in guiding learning-based approaches. Instructor: Adhikari.

Ph 50 ab. Caltech Physics League. *3 units (1-0-2); first, second terms. Prerequisites: Ph 1 abc.* This course serves as a physics club, meeting weekly to discuss and analyze real-world problems in physical sciences. A broad range of topics will be considered, such as energy production, space and atmospheric phenomena, astrophysics, nano-science, and others. Students will use basic physics knowledge to produce simplified

(and perhaps speculative) models of complex natural phenomena. In addition to regular assignments, students will also compete in solving challenge problems each quarter with prizes given in recognition of the best solutions. Not offered 2025-26.

Ph 70. Oral and Written Communication. *6 units (2-0-4); first, second terms.* Provides practice and guidance in oral and written communication of material related to contemporary physics research. Students will choose a topic of interest, make presentations of this material in a variety of formats, and, through a guided process, draft and revise a technical or review article on the topic. The course is intended for senior physics majors. Fulfills the Institute scientific writing requirement. Instructor: Hitlin.

Ph 77 abc. Advanced Physics Laboratory. *9 units (0-5-4); first, second, third terms. Prerequisites: Ph 7 or instructor's permission.* Advanced preparation for research in experimental physics. Focused "tracks" include: 1) electronic signal acquisition and processing, spectral analysis, feedback control, and practical experience using electronics test equipment; 2) optical techniques including imaging, interferometry, laser frequency stabilization, optical resonators, and LIDAR; 3) atomic processes including optical pumping, nuclear magnetic resonance, and saturated absorption spectroscopy. Tracks may be taken in any order, and each requires one term to complete. Special topics and student-led projects may be available on request. Instructors: Black, Libbrecht.

Ph 78 abc. Senior Thesis (Experiment). *9 units; first, second, third terms. Prerequisites: To register for this course, the student must obtain approval of the chair of the Physics Undergraduate Committee (Ken Libbrecht).* Open only to senior physics majors. Experimental research must be supervised by a faculty member, the student's thesis adviser. Two 15-minute presentations to the Physics Undergraduate Committee are required, one near the end of the first term and one near the end of third term. The written thesis must be completed and distributed to the committee one week before the second presentation. Students wishing assistance in finding an adviser and/or a topic for a senior thesis are invited to consult with the chair of the Physics Undergraduate Committee, or any other member of this committee. A grade will not be assigned in Ph 78 until the end of the third term. P grades will be given the first two terms, and then changed at the end of the course to the appropriate letter grade. Not offered on a pass/fail basis.

Ph 79 abc. Senior Thesis (Theory). *9 units; first, second, third terms. Prerequisites: To register for this course, the student must obtain approval of the chair of the Physics Undergraduate Committee (Ken Libbrecht).* Open only to senior physics majors. Theoretical research must be supervised by a faculty member, the student's thesis adviser. Two 15-minute presentations to the Physics Undergraduate Committee are required, one near the end of the first term and one near the end of third term. The written thesis must be completed and distributed to the committee one week before the second presentation. Students wishing

assistance in finding an adviser and/or a topic for a senior thesis are invited to consult with the chair of the Physics Undergraduate Committee, or any other member of this committee. A grade will not be assigned in Ph 79 until the end of the third term. P grades will be given the first two terms, and then changed at the end of the course to the appropriate letter grade. Not offered on a pass/fail basis.

Ph 101. Order-of-Magnitude Physics. *9 units (3-0-6); third term.* Emphasis will be on using basic physics to understand complicated systems. Examples will be selected from properties of materials, geophysics, weather, planetary science, astrophysics, cosmology, biomechanics, etc. Given in alternate years. Not offered 2025-26.

Ay/Ph 104. Relativistic Astrophysics. *9 units (3-0-6);* For course description, see Astrophysics

Ph 105. Analog Electronics for Physicists. *9 units; first term. Prerequisites: Ph 1 abc, Ma 2, or equivalent.* A laboratory course intended for graduate students, it covers the design, construction, and testing of simple, practical analog and interface circuits useful for signal conditioning and experiment control in the laboratory. No prior experience with electronics is required. Students will use operational amplifiers, analog multipliers, diodes, bipolar transistors, and passive circuit elements. Each week includes a 45 minute lecture/recitation and a 2½ hour laboratory. The course culminates in a two-week project of the student's choosing. Instructors: Rice, Libbrecht.

Ph 106 abc. Topics in Classical Physics. *9 units (4-0-5); first, second, third terms. Prerequisites: Ph 2 ab or Ph 12 abc, Ma 2.* An intermediate course in the application of basic principles of classical physics to a wide variety of subjects. Ph 106 a will be devoted to mechanics, including Lagrangian and Hamiltonian formulations of mechanics, small oscillations and normal modes, central forces, and rigid-body motion. Ph 106 b will be devoted to fundamentals of electrostatics and magnetostatics, including boundary-value problems, multipole expansions, and electrostatics and magnetostatics in matter. Ph106 c will cover electrodynamics, including conservation laws, potential theory, electromagnetic waves, and radiation as well as the relationship between special relativity and electrodynamics. Instructors: Chatziiaonnou, Most.

Ph 107. Classical and Laser Optics. *9 units (3-0-6); third term. Prerequisites: Ph 2 ab or Ph 12 ab.* An introduction and overview of classical and laser optics. We will develop tools and concepts to understand the behavior of light, such as ray transfer matrix analysis, wave optics, diffraction, coherence, interference, and polarization. These tools will then be used to understand the action of optical elements, imaging, resonators, waveguides, fiber optics, Gaussian beams, interferometers, and other techniques and concepts commonly encountered in research settings. Instructor: Hutzler.

APh/Ph 112. Stochastic Resonance Phenomena and the Essential Role of Noise. *9 units (3-0-6);* For course description, see Applied Physics

Ph/APh/EE/BE 118 ab. Physics of Measurement. *9 units (3-0-6); second term. Prerequisites: Ph 127, APh 105, or equivalent, or permission from instructor.* This course explores the fundamental underpinnings of experimental measurements from the perspectives of information, noise, coupling, responsivity, and backaction. Its overarching goal is to enable students to develop intuition about a diversity of real measurement systems and the means to critically evaluate them. This involves developing a standard framework for estimating the ultimate and practical limits to information that can be extracted from a real measurement system. Topics will include the fundamental nature of information and signals, physical signal transduction and responsivity, the physical origin of noise processes, modulation, frequency conversion, synchronous detection, signal-sampling techniques, digitization, signal transforms, spectral analyses, and correlation methods. The first term will cover the essential underpinnings, while second-term topics will vary year-by-year according to interest. Among possible Ph 118 b topics are: high frequency, microwave, and fast time-domain measurements; biological interfaces and biosensing; the physics of functional brain imaging; and quantum measurement. Part b not offered 2025-26. Instructor: Roukes.

Ph/APh/EE 118 c. Physics of Measurement: Moonbounce and Beyond - Microwave Scattering for Communications and Metrology. *9 units (3-0-6); third term. Prerequisites: Ph 118a, and a course in microwave physics and engineering (e.g., Ph 118b, EE 153, or equivalent), or permission from the instructor.* In 1944, the possibility of bouncing radio waves off the moon was first discovered inadvertently. Since then, radio wave echoes have been recorded from other planets, asteroids, tropospheric disturbances, and airplanes aloft. Microwave scattering provides a rich platform enabling exploration of long-range microwave communications, remote sensing, and interesting astrophysical measurements. This class will cover the physics of microwave propagation and scattering, low-earth orbit (LEO) satellite trajectories and communications, moonbounce, and the principles of ultrasensitive instrumentation - for both transmitting and receiving - enabling remote sensing with microwaves. One formal lecture per week will cover the fundamentals. The second weekly class meeting will be an extended hands-on workshop - starting mid-afternoon and going on into the evening - to assemble all aspects of a high-power microwave scattering system operating at 23cm. Students will set up tracking software for satellites and planetary objects, assemble an ultrasensitive software-defined radio (SDR) system, implement 1kW microwave power amplification at 23cm, and explore antenna and feed horn theory and practice. Also implemented will be powerful weak signal communications methods pioneered by Prof. Joe Taylor (Physics, Princeton) enabling ultraweak signal extraction through GPS synchronization of remote sources and receivers. We will employ

Caltech's fantastic resource for this project - a 6-meter diameter microwave dish atop Moore Laboratory. Prospective students are encouraged to obtain an FCC Technician license (or higher) prior to spring term to permit their operation of the system. For information see: http://www.its.caltech.edu/~w6ue/. Instructor: Roukes.

CS/Ph 120. Quantum Cryptography. *9 units (3-0-6);* For course description, see Computer Science

Ph 121 abc. Computational Physics Lab. *6 units (0-6-0); first, second, third terms.* Many of the recent advances in physics are attributed to progress in computational power. In the advanced computational lab, students will hone their computational skills by working through projects inspired by junior level classes (such as classical mechanics and E, statistical mechanics, quantum mechanics and quantum many-body physics). This course will primarily be in Python and Mathematica. This course is offered pass/fail. Instructors: Simmons-Duffin, Huang.

Ph 125 abc. Quantum Mechanics. *9 units (4-0-5); first, second, third terms. Prerequisites: Ma 2 ab, Ph 12 abc or Ph 2 ab, or equivalents.* A one-year course in quantum mechanics and its applications, for students who have completed Ph 12 or Ph 2. Wave mechanics in 3-D, scattering theory, Hilbert spaces, matrix mechanics, angular momentum, symmetries, spin-1/2 systems, approximation methods, identical particles, and selected topics in atomic, solid-state, nuclear, and particle physics. Instructor: Porter.

Ph 127 ab. Statistical Physics of Interacting Systems, Phases, and Phase Transitions. *9 units (4-0-5); first, second terms. Prerequisites: Ph 12 c or equivalent; quantum mechanics at the level of Ph 125 ab is required for Ph 127 b; may be taken concurrently.* An advanced course in statistical physics that focuses on systems of interacting particles. Part a will cover interacting gases and spin models of magnetism, phase transitions and broken symmetries, classical field theories, and renormalization group approach to collective phenomena. Part b will introduce the path-integral based quantum to classical statistical mechanics mapping, as well as dualities and topological-defects descriptions, with applications to magnets, superfluids, and gauge field theories. Instructor: Motrunich.

Ph 129 abc. Mathematical Methods of Physics. *9 units (4-0-5); second, third terms. Prerequisites: Ma 2 and Ph 2 abc, or equivalent.* Mathematical methods and their application in physics. First term focuses on group theoretic methods in physics. Second term includes analytic methods such as complex analysis, differential equations, integral equations and transforms, and other applications of real analysis. Third term covers probability and statistics in physics. Each part may be taken independently. Part a not offered 2025-26. Instructors: Y. Chen, Kapustin.

Ph 135. Introduction to Condensed Matter. *9 units (3-0-6); first term. Prerequisites: Ph 125 ab or equivalent or instructor's permission.* This course is an introduction to condensed matter which covers electronic properties of solids, including band structures, and transport. In addition, the course will introduce topological band-structure effects, covering Berry phase, the Thouless pump, and topological insulators. Ph 135 is continued by Ph/APh 223 ab in the winter and spring terms. Instructor: Ye.

Ph 136 abc. Applications of Classical Physics. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 106 ab or equivalent.* Applications of classical physics to topics of interest in contemporary "macroscopic" physics. Continuum physics and classical field theory; elasticity and hydrodynamics; plasma physics; magnetohydrodynamics; thermodynamics and statistical mechanics; gravitation theory, including general relativity and cosmology; modern optics. Content will vary from year to year, depending on the instructor. An attempt will be made to organize the material so that the terms may be taken independently. Ph 136 a will focus on thermodynamics, statistical mechanics, random processes, and optics. Ph 136 b will focus on fluid dynamics, MHD, turbulence, and plasma physics. Ph 136 c will cover an introduction to general relativity. Given in alternate years. Not offered 2025-26.

Ph/APh 137 ab. Atoms and Photons. *9 units (3-0-6); first, second terms. Prerequisites: Ph 125 ab or equivalent, or instructor's permission.* This course will provide an introduction to the interaction of atomic systems with photons. Each term can be taken independent of each other. The main emphasis is on laying the foundation for understanding current research that utilizes cold atoms and quantized light fields. First term: quantization of light fields, quantized light matter interaction, open system dynamics, entanglement, master equations, quantum jump formalism. Applications to cavity QED, optical lattices, and Rydberg arrays. Second term: resonance phenomena, atomic structure, and the semi-classical interaction of atoms with static and oscillating electromagnetic fields. Techniques such as laser cooling/trapping, coherent manipulation and control of atomic systems. Instructors: Endres, Hutzler.

APh/Ph 138 ab. Quantum Hardware and Techniques. *9 units (3-0-6);* For course description, see Applied Physics

Ph 139. Introduction to Elementary Particle Physics. *9 units (3-0-6); second term. Prerequisites: Ph 125 ab or equivalent, or instructor's permission.* This course provides an introduction to particle physics which includes Standard Model, Feynman diagrams, matrix elements, electroweak theory, QCD, gauge theories, the Higgs mechanism, neutrino mixing, astro-particle physics/cosmology, accelerators, experimental techniques, important historical and recent results, physics beyond the Standard Model, and major open questions in the field. Instructor: Porter.

APh/Ph/MS 152. Fundamentals of Fluid Flow in Small Scale Systems. *9 units (3-0-6);* For course description, see Applied Physics

APh/Ph/Ae/MS 153. Fundamentals of Energy and Mass Transport in Small Scale Systems. *9 units (3-0-6);* For course description, see Applied Physics

Ph 171. Reading and Independent Study. *Units in accordance with work accomplished;* Occasionally, advanced work involving reading, special problems, or independent study is carried out under the supervision of an instructor. Approval of the instructor and of the student's departmental adviser must be obtained before registering. Graded pass/fail.

Ph 172. Research in Physics. *Units in accordance with work accomplished;* Undergraduate students registering for 6 or more units of Ph 172 must provide a brief written summary of their work to the option rep at the end of the term. Approval of the student's research supervisor and departmental adviser must be obtained before registering. Graded pass/fail.

Ph 177. Advanced Experimental Physics. *9 units (0-4-5); second, third terms. Prerequisites: Ph 6, Ph 106 a, Ph 125 a or equivalents.* A one-term laboratory course which will require students to design, assemble, calibrate, and use an apparatus to conduct a nontrivial experiment involving quantum optics or other current research area of physics. Students will work as part of a small team to reproduce the results of a published research paper. Each team will be guided by an instructor who will meet weekly with the students; the students are each expected to spend an average of 4 hours/week in the laboratory and the remainder for study and design. Enrollment is limited. Permission of the instructors required. Instructor: Rice.

CNS/Bi/Ph/CS/NB 187. Neural Computation. *9 units (3-0-6);* For course description, see Computation & Neural Systems

Ph 198. Special Topics in Physics. *Units in accordance with work accomplished;* Topics will vary year to year and may include hands-on laboratory work, team projects and a survey of modern physics research. Instructor: Staff.

Ph 201. Candidacy Physics Fitness. *9 units (3-0-6); third term.* The course will review problem solving techniques and physics applications from the undergraduate physics college curriculum. In particular, we will touch on the main topics covered in the written candidacy exam: classical mechanics, electromagnetism, statistical mechanics and quantum physics, optics, basic mathematical methods of physics, and the physical origin of everyday phenomena. Instructor: Endres.

Ph 203. Nuclear Physics. *9 units (3-0-6); third term. Prerequisites: Ph 125 or equivalent.* An introduction and overview of modern topics in

nuclear physics, including models and structure of nucleons, nuclei and nuclear matter, the electroweak interaction of nuclei, and nuclear/neutrino astrophysics. Instructor: Filippone.

Ph 205 abc. Relativistic Quantum Field Theory. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 125.* Topics: the Dirac equation, second quantization, quantum electrodynamics, scattering theory, Feynman diagrams, non-Abelian gauge theories, Higgs symmetry-breaking, anomalies, the Weinberg-Salam model, and renormalization. Instructor: Wise.

Ph/CS 219 abc. Quantum Computation. *9 units (3-0-6); first, second, third terms. Prerequisites: Ph 125 ab or equivalent.* The theory of quantum information and quantum computation. Overview of classical information theory, compression of quantum information, transmission of quantum information through noisy channels, quantum error-correcting codes, quantum cryptography and teleportation. Overview of classical complexity theory, quantum complexity, efficient quantum algorithms, fault-tolerant quantum computation, physical implementations of quantum computation. Instructors: Kitaev, Preskill.

Ph 220. Quantum Learning Theory. *9 units (3-0-6); first term. Prerequisites: Ph 125 ab or equivalent.* This course covers quantum learning theory, a contemporary field at the intersection of quantum mechanics, quantum computing, statistical learning theory, and machine learning. The fundamental questions explored include: how to efficiently learn quantum many-body systems? When can quantum machines learn and predict better than classical machines? What physical phenomena can quantum machines learn and discover? The course aims to develop rigorous theoretical foundations for understanding how scientists, machines, and future quantum computers can learn and discover new phenomena in our quantum-mechanical universe. Instructor: Huang.

Ph 221. Experimental Techniques in AMO Physics. *9 units (3-0-6); first term. Prerequisites: Ph 125 ab or equivalent, or instructor's permission.* This course provides an introduction to key experimental techniques in atomic, molecular, and optical (AMO) physics. Topics include noise and random processes, feedback and control theory, electronics, photon detection, and optics. These concepts are explored through their applications in modern quantum-science experiments, such as optical atomic clocks and neutral-atom quantum computers. The course is designed to equip students with the technical foundation necessary to understand, improve, and develop advanced experimental systems in typical AMO laboratories. Instructor: Oppong.

Ph/APh 223 ab. Advanced Condensed-Matter Physics. *9 units (3-0-6); second, third terms. Prerequisites: Ph 135 or equivalent, or instructor's permission.* Advanced topics in condensed-matter physics, with emphasis on the effects of interactions, symmetry, and topology in many-body systems. Ph/APh 223 a covers second quantization, Hartree-Fock theory of the electron gas, Mott insulators and quantum

magnetism, spin liquids, bosonization, and the integer and fractional quantum Hall effect. Ph/APh 223 b continues with superfluidity and superconductivity; topics include the Bose-Hubbard model, Ginzburg-Landau theory, BCS theory, tunneling signatures of superconductivity, Josephson junctions, superconducting qubits, and topological superconductivity. Instructor: Alicea.

Ph 229 abc. Advanced Mathematical Methods of Physics. *9 units (3-0-6); second, third terms. Prerequisites: Ph 129 abc or equivalent.* Advanced topics in geometry and topology that are widely used in modern theoretical physics. Emphasis will be on understanding and applications more than on rigor and proofs. First term will cover basic concepts in topology and manifold theory. Second term will include Riemannian geometry, fiber bundles, characteristic classes, and index theorems. Third term will include anomalies in gauge-field theories and the theory of Riemann surfaces, with emphasis on applications to string theory. Not offered 2025-26.

Ph 230 abc. Elementary Particle Theory. *9 units (3-0-6); second, third terms. Prerequisites: Ph 205 abc or equivalent.* First term: Standard model, including electroweak and strong interactions, symmetries and symmetry breaking (including the Higgs mechanism), parton model and quark confinement, anomalies. Second and third terms: more on nonperturbative phenomena, including chiral symmetry breaking, instantons, the 1/N expansion, lattice gauge theories, and topological solitons. Other topics include topological field theory, precision electroweak, flavor physics, conformal field theory and the AdS/CFT correspondence, supersymmetry, Grand Unified Theories, and Physics Beyond the Standard Model. Part c not offered 2025-26. Instructor: Papucci.

Ph 231 ab. Advanced Topics in Statistical Mechanics. *9 units (3-0-6); second, third terms. Prerequisites: Ph 127 or equivalent.* The course covers rigorous results in classical and quantum statistical mechanics of lattice systems. Winter quarter: basic lattice models, existence of the thermodynamic limit, phase transitions at positive temperature, Hohenberg-Mermin-Wagner and Goldstone theorems. Spring quarter: C*-algebraic approach to statistical mechanics, locality and dynamics in quantum systems (Lieb-Robinson bounds), topological invariants of gapped quantum systems at zero temperature, Symmetry Protected Topological Phases. Not offered 2025-26.

Ph 232. Introduction to Topological Field Theory. *9 units (3-0-6); first term. Prerequisites: Ph 205.* Topological field theories are the simplest examples of quantum field theories which, in a sense, are exactly solvable and generally covariant. During the past twenty years they have been the main source of interaction between physics and mathematics. Thus, ideas from gauge theory led to the discovery of new topological invariants for 3-manifolds and 4-manifolds. By now, topological quantum field theory (TQFT) has evolved into a vast subject, and the main goal of this course is to give an accessible introduction to this elegant subject.

Not offered 2025-26.

Ph 235 ab. Theoretical Cosmology and Astroparticle Physics. *9 units (3-0-6); second, third terms. Prerequisites: General Relativity at the level of Ph 236 a, and Quantum Field Theory at the level of Ph 205 a.* Second term: Cosmology in an expanding universe, inflation, big bang nucleosynthesis, baryogenesis, theories of dark matter, neutrino and nuclear astrophysics. Third term: Cosmological perturbation theory and the cosmic microwave background, structure formation. Instructors: Zurek, Bock.

Ph 236 abc. General Relativity. *9 units (3-0-6); first, second terms. Prerequisites: a mastery of special relativity at the level of Goldstein's Classical Mechanics, or of Jackson's Classical Electrodynamics.* A systematic exposition of Einstein's general theory of relativity and its applications to gravitational waves, black holes, relativistic stars, causal structure of space-time, cosmology and brane worlds. Given in alternate years. Part c not offered 2025-26. Instructors: Chatziiaonnou, Teukolsky.

Ph 237. Gravitational Radiation. *9 units (3-0-6); third term. Prerequisites: Ph 106 b, Ph 12 b or equivalents.* Special topics in Gravitational-wave Detection. Physics of interferometers, limits of measurement, coherent quantum feedback, noise, data analysis. Instructor: Y. Chen.

Ph 242 ab. Physics Seminar. *4 units (2-0-2); first, second terms.* An introduction to independent research, including training in relevant professional skills and discussion of current Caltech research areas with Caltech faculty, postdocs, and students. One meeting per week plus student projects. Registration restricted to first-year graduate students in physics. Instructor: Hsieh.

Ph 250 ab. Introduction to String Theory. *9 units (3-0-6); second, third terms. Prerequisites: Ph 205 or equivalent.* Ph 250 a will cover the worldsheet formulation of string theory, including conformal field theory, supersymmetry, the emergence of gravity, scattering amplitudes, T-duality, and D-branes. We will also discuss how to build semi-realistic models of elementary particle physics from string theory. Ph 250 b will cover advanced topics such as non-perturbative dualities, Calabi-Yau geometry and mirror symmetry, black holes, the holographic principle and its relation to quantum information theory, and constraints on gravitational theories. Not offered 2025-26.

Ph 300. Thesis Research. *Units in accordance with work accomplished;* Ph 300 is elected in place of Ph 172 when the student has progressed to the point where research leads directly toward the thesis for the degree of Doctor of Philosophy. Approval of the student's research supervisor and department adviser or registration representative must be obtained before registering. Graded pass/fail.

POLITICAL SCIENCE

PS 12. Introduction to Political Science. *9 units (3-0-6); second, third terms.* Introduction to the tools and concepts of analytical political science. Subject matter is primarily American political processes and institutions. Topics: spatial models of voting, redistributive voting, games, presidential campaign strategy, Congress, congressional-bureaucratic relations, and coverage of political issues by the mass media. Instructors: Hirsch, Kiewiet.

PS 20. Political-Economic Development and Material Culture. *9 units (3-0-6); second term.* During the 19th-century the American economy, despite the Civil War, caught up to and surpassed all European economies. How did the likes of Singer, John Deere and Seth Thomas - latecomers to the markets they served-come to dominate those markets both domestically and internationally? Why did the technology of interchangeable parts and mass production become known as 'the American system' when much of that technology was imported from Europe? What role did government play in facilitating or thwarting innovation and economic growth? This course will explore such questions as reflected in the ordinary things people collect under the label 'antiques'. What do we learn from the fact that we can document a half dozen American manufacturers of apple peelers but not a single comparable European company? Why is the hand sewn quilt a nearly unique American folk art form and what does the evolution of quilting patterns tell us about technology and economic prosperity? What do baking powder cans as a category of collectible tell us about the politics of federal versus state regulation? Students will be expected to each choose a topic that asks such questions and to explore possible answers, all with an eye to understanding the interplay of economics, politics, and demography. Not offered 2025-26.

PS 97. Undergraduate Research. *Units to be arranged; any term. Prerequisites: advanced political science and instructor's permission.* This course offers advanced undergraduates the opportunity to pursue research in political science individually or in a small group. Graded pass/fail.

PS 101. Selected Topics in Political Science. *Units to be determined by arrangement with the instructor; offered by announcement.* Instructor: Staff.

PS 120. American Electoral Behavior and Party Strategy. *9 units (3-0-6); third term.* A consideration of existing literature on the voting behavior of the citizen, and an examination of theoretical and empirical views of the strategies followed by the parties. Two substantial papers are expected of students. Not offered 2025-26.

PS 121. Analyzing Congress. *9 units (3-0-6); first term.* Introduction to the US Congress with an emphasis on thinking analytically and

empirically about the determinants of Congressional behavior. Among the factors examined are the characteristics and incentives of legislators, rules governing the legislative process and internal organization, separation of powers, political parties, Congressional elections, and interest group influence. Not offered 2025-26.

PS 122. Political Representation. *9 units (3-0-6); third term. Prerequisites: PS 12.* Why does the U.S. Constitution feature separation of powers and protect states' rights? Should the Senate have a filibuster? When can Congress agree on the best policy for the country (and what does "best" even mean)? This course uses a rigorous set of tools including game theory and social choice to help students understand the effectiveness of American democracy to represent diverse interests. Using the tools, we study U.S. electoral systems, Congress, federalism, and the courts, with a focus on understanding how the country has tried to overcome the challenges of group decision making and the inevitable conflicts that arise between the branches of government and divided political interests. Students will leave the course with a deeper understanding of how rules and strategy shape U.S. democracy. Not offered 2025-26.

PS 123. Regulation and Politics. *9 units (3-0-6); second term. Prerequisites: PS 12.* This course will examine the historical origins of several regulatory agencies and trace their development over the past century or so. It will also investigate a number of current issues in regulatory politics, including the great discrepancies that exist in the cost-effectiveness of different regulations, and the advent of more market-based approaches to regulations instead of traditional "command-and-control." Not offered on a pass/fail basis. Instructor: Kiewiet.

Ec/PS 124. Identification Problems in the Social Sciences. *9 units (3-0-6);* For course description, see Economics

PS 125. Analyzing Political Conflict and Violence. *9 units (3-0-6); second term.* This course examines the causes of and solutions for conflict and violence: Why do wars occur and how do we stop them? We cover topics such as terrorism, ethnic violence, civil wars, the Israeli-Palestinian conflict, repression, revolutions, and inter-state wars. We study these phenomena using the rational choice framework and modern tools in data analysis. The goals of the class are to explain conflicts and their terminations as outcomes of strategic decision-making and to understand the empirical strengths and weakness of current explanations. Instructor: Gibilisco.

IDS/Ec/PS 126. Applied Data Analysis. *9 units (3-0-6);* For course description, see Information and Data Sciences

An/PS 127. Corruption. *9 units (3-0-6);* For course description, see Anthropology

PS/Ec 128. Introduction to Public Health Economics and Policy. *9 units (3-0-6); third term.* This course will cover the basic concepts and principles of health economics and challenges in health policy implementation. By studying this course, students will establish economic thinking and be able to flexibly use economic methods to analyze practical problems in the field of health care. Students will also learn about the application of machine learning in public health. This course combines theory and methodology. The teaching goal focuses on students' ability to analyze and solve practical problems. Interactive teaching is done through group discussions and topic debates around case studies. Each chapter consists of a theory and case analysis. The case discussion will focus on basic theories and methods and highlight the hot issues in the current medical and health system. The exam will be an open-book exam, with class discussions accounting for 40%, and the final exam accounting for 60%. Not offered 2025-26.

PS 129. American Parties, Partisanship, and Polarization. *9 units (3-0-6); second term.* Partisan polarization has been at the forefront of American politics for years. Its negative effects on society are clear, and many voters and political elites agree that unchecked partisan polarization causes harm to our democratic institutions. Yet, it also feels like these social divisions are not improving anytime soon. If most people agree that Republicans and Democrats just need to get along, then why are we still so divided by partisanship? Why did this divide emerge in the first place? And if polarization is a defining problem of American politics today, what can be done to alleviate or at least mitigate its effects? This course will explore these questions by discussing relevant literature on American political parties, voter partisanship, and partisan polarization. Through reading a mix of academic research as well as political and cultural journalism, students will learn more about the history of the modern Democratic and Republican parties; trends in voter behavior and partisanship, including how partisanship varies across different subgroups of voters; and recent research on the causes and consequences of modern partisan polarization. By the end of the course, students will have an improved understanding of American partisanship and how it impacts many of today's most pressing policy issues. Instructor: Centeno.

PS 132. Formal Theories in Political Science. *9 units (3-0-6); second term. Prerequisites: PS 12 and PS/Ec 172.* Axiomatic structure and behavioral interpretations of game theoretic and social choice models and models of political processes based on them. Not offered 2025-26.

PS 135. Analyzing Legislative Elections. *9 units (3-0-6); first term.* The purpose of this course is to understand legislative elections. The course will study, for example, what role money plays in elections and why incumbents do better at the polls. It will also examine how electoral rules impact the behavior both of candidates and voters, and will explore some of the consequences of legislative elections, such as divided government. Not offered 2025-26.

PS 139. Comparative Politics. *9 units (3-0-6); second term. Prerequisites: PS 12.* This course offers a broad introduction to the theoretical and empirical research in comparative political economy. An emphasis will be placed on the parallel process of political and economic development and its consequences on current democratic political institutions such as: electoral rules, party systems, parliamentary versus presidential governments, legislatures, judicial systems, and bureaucratic agencies as exemplified in central bank politics. We will study the differential impact of these political institutions on the type of policies they implement and the economic outcomes they produce. The main objective of the course will be to assess the robustness of the analyzed theories in light of their empirical support, coming mainly from statistical analysis. Instructor: Lopez-Moctezuma.

PS 141 ab. A History of Budgetary Politics in the United States. *9 units (3-0-6); first, third terms.* This class will examine budgetary conflict at key junctures in U.S. history. Topics include the struggle to establish a viable fiscal system in the early days of the Republic, the ante bellum tariff, the "pension politics" of the post-Civil War era, the growth of the American welfare state, and the battle over tax and entitlement reform in the 1980s and 1990s. Instructor: Kiewiet.

PS/Ec 172. Game Theory. *9 units (3-0-6); third term. Prerequisites: Ec 11 or PS 12 and one from the following list: ACM 116, ACM 117, Ma 3, or Ma/ACM/IDS 140 ab.* This course is an introduction to non-cooperative game theory, with applications to political science and economics. It covers the theories of normal-form games and extensive-form games, and introduces solutions concepts that are relevant for situations of complete and incomplete information. The basic theory of repeated games is introduced. Applications are to auction theory and asymmetric information in trading models, cheap talk and voting rules in congress, among many others. Instructor: Pomatto.

PSYCHOLOGY

Psy 13. Introduction to Cognitive Neuroscience. *9 units (3-0-6); third term.* This course will provide an introduction to what we know about the fascinating link between the brain, the mind, and behavior. We will start with a basic review of the brain as a biological organ, its evolution, development, and its basic operations including visual and others' senses. Next, we will discuss how the brain gives rise to a wide variety of complex behaviors, memory, social and emotional behaviors. The course will finally introduce students to the wider neurophilosophical questions concerning freewill, death and morality. Instructor: Mobbs.

Psy 25. Reading and Research in Psychology. *Units determined by the instructor;* Not available for credit toward humanities-social science requirement. Written report required. Graded pass/fail. Not offered 2025-26.

Psy 101. Selected Topics in Psychology. *Units determined by arrangement with the instructor; offered by announcement.* Instructor: Staff.

CNS/Psy/Bi 102 a. Social and Decision Neuroscience. *9 units (3-0-6);* For course description, see Computation & Neural Systems

CNS/Psy/Bi 102 b. Social and Decision Neuroscience. *9 units (3-0-6);* For course description, see Computation & Neural Systems

Psy/CNS 105 ab. Frontiers in Neuroeconomics. *5 units (1.5-0-3.5); first and second terms.* The new discipline of Neuroeconomics seeks to understand the mechanisms underlying human choice behavior, born out of a confluence of approaches derived from Psychology, Neuroscience and Economics. This seminar will consider a variety of emerging themes in this new field. Some of the topics we will address include the neural bases of reward and motivation, the neural representation of utility and risk, neural systems for inter-temporal choice, goals vs habits, and strategic interactions. We will also spend time evaluating various forms of computational and theoretical models that underpin the field such as reinforcement-learning, Bayesian models and race to barrier models. Each week we will focus on key papers and/or book chapters illustrating the relevant concepts. Not offered 2025-26.

Ec/Psy 106. Behavioral Game Theory. *9 units (3-0-6);* For course description, see Economics

Ec/Psy 108. Foundations of Behavioral Economics. *9 units (3-0-6);* For course description, see Economics

Ec/Psy 109. Frontiers in Behavioral Economics. *9 units (3-0-6);* For course description, see Economics

Psy 115. Social Psychology. *9 units (3-0-6); first term.* The study of how people think about other people and behave toward or around others. Topics include social cognition and emotions (theory of mind and empathy), their development from childhood to old age, impairments in social functions, altruism and cooperation, social groups (ingroup and outgroup), attribution and stereotypes. The class also presents evidence on how these social phenomena are implemented in the human brain and introduces behavioral and neuroscientific methods used in social psychology and social neuroscience. Not offered 2025-26.

Psy 120. Metascience: The Science of Being An Impactful Scientist. *9 units (3-0-6); third term. Prerequisites: There are no prerequisites, but having taken NB/Bi/CNS 150 would be advantageous.* This course will provide the student with a unique insight into the skills used by successful scientists in the social sciences, with the focus being on psychology and cognitive neuroscience (although this is interesting for

any type of science career). The course promotes active (hands on) learning, to enhance skills such as creative idea formation, theory, science communication including presentation and writing skills for the public. The class will also provide discussion on practices and expert opinions on what departments looks for when recruiting students and hiring faculty. Enrollment limited to 14 students. Instructor: Mobbs.

Psy 125. Reading and Research in Psychology. *Units determined by the instructor;* Same as Psy 25, but for graduate credit. Not available for credit toward humanities-social science requirement. Not offered 2025-26.

Psy/CNS 130. Introduction to Human Memory. *9 units (3-0-6); second term.* The course offers an overview of experimental findings and theoretical issues in the study of human memory. Topics include iconic and echoic memory, working memory, spatial memory, implicit learning and memory; forgetting: facts vs. skills, memory for faces; retrieval: recall vs. recognition, context-dependent memory, semantic memory, spreading activation models and connectionist networks, memory and emotion, infantile amnesia, memory development, and amnesia. Not offered 2025-26.

Psy/CNS 132. Computational Reinforcement-learning in Biological and Non-biological Systems. *9 units (3-0-6); second term.* Reinforcement-learning concerns the computational principles by which animals and artificial agents can learn to select actions in their environment in order to maximize their future rewards. Over the past 50 years there has been a rich interplay between the development and application of reinforcement-learning models in artificial intelligence, and the investigation of reinforcement-learning in biological systems, including humans. This course will review this rich literature, covering the psychology of animal-learning, the neurobiology of reward and reinforcement, and the theoretical basis and application of reinforcement-learning models to biological and non-biological systems. Not offered 2025-26.

Psy 133. Computation, Cognition and Consciousness. *9 units (3-0-6); second term.* This course will critically examine the impact of recent advances in computational neuroscience for central problems of philosophy of mind. Beginning with a historical overview of computationalism (the thesis that mental states are computational states), the course will examine how psychological explanation may be understood in computational terms across a variety of levels of description, from sub-neuronal and single neuroncomputation to circuit and network levels. Specific issues will include: whether computation provides unifying psychological principles across species; whether specific mental states such as pain are computational states; digital/analog computation, dynamical systems, and mental representation; whether conscious experience can be understood as a computational process. Not offered 2025-26.

Pl/CNS/NB/Bi/Psy 167. Consciousness. *9 units (3-0-6);* For course description, see Philosophy

CNS/Bi/Psy/NB 176. Cognition. *9 units (4-0-5);* For course description, see Computation & Neural Systems

Psy/Bi/CNS 255. Topics in Emotion and Social Cognition. *9 units (3-0-6); second term. Prerequisites: NB/Bi/CNS 150 or instructor's permission.* Emotions are at the forefront of most human endeavors. Emotions aid us in decision-making (gut feelings), help us remember, torment us, yet have ultimately helped us to survive. Over the past few decades, we have begun to characterize the neural systems that extend from primitive affective response such as fight or flight to the complex emotions experienced by humans including guilt, envy, empathy and social pain. This course will begin with an in-depth examination of the neurobiological systems that underlie negative and positive emotions and move onto weekly discussions, based on assigned journal articles that highlight both rudimentary and complex emotions. The final weeks will be devoted to exploring how the neurobiological systems are disrupted in affective disorders including anxiety, aggression and psychopathy. In addition to these discussions and readings, each student will be required to write a review paper or produce a short movie on a topic related to one of the emotions discussed in these seminars and its underlying neural mechanisms. Instructor: Mobbs.

Psy 283 abc. Graduate Proseminar in Social and Decision Neuroscience. *3 units (1.5-0-1.5); first, second, third terms.* The course involves student presentations of their research, reading and discussion of recent research in social and decision neuroscience, and development of professional skill such as scientific writing and speaking, research ethics, writing grants and peer review. This course is only open to graduate students in the Social and Decision Neuroscience, Computational and Neural Systems and Social Science PhD programs. Instructors: O'Doherty, Rangel, O'Doherty.

SS/Psy/CNS 285. Topics in Social, Cognitive, and Decision Sciences. *3 units (1.5-0-1.5);* For course description, see Social Science

SCIENTIFIC AND ENGINEERING COMMUNICATION

SEC 10. Technical Seminar Presentations. *3 units (3-0-0); first, second, third terms.* (Seniors required to take this course are given priority in registration.) The purpose of this course is to equip students with the skills, knowledge, and experience necessary to give effective oral presentations. The course will include a mix of formal instruction, group discussions, practice presentations, and individual feedback. Limited enrollment. May not be repeated for credit. Instructor: Gold.

SEC 11. Written Academic Communication in Engineering and Applied Science. *3 units (1-0-2); terms to be arranged.* This class provides the opportunity for students to gain experience in academic technical writing in engineering and applied science. Students will choose a technical topic of interest, possibly based on a previous research or course project, and write a paper in an academic genre on that topic. Appropriate genres include the engineering report, review paper, or a peer-reviewed journal paper. Students will receive instruction in academic discourse in engineering and applied sciences as well as substantial feedback on their work-in-progress. This course is recommended for students who plan to attend graduate school or who wish to work toward a senior thesis or academic publication. Fulfills the Institute scientific writing requirement. For Winter and Spring terms, seniors will be given priority; however this class is open to all students in EAS and GPS, and to students in other divisions as space allows. Instructors: Burkett, Meyer, George.

SEC 12. Written Professional Communication in Engineering and Applied Science. *3 units (1-0-2); terms to be arranged.* This class introduces students to common workplace genres of writing in professional (non-academic) fields in engineering and the applied sciences. Students will study and practice effective writing strategies within these genres and consider the varied audiences and goals of communicating in engineering and applied science industries. Genres covered may include job applications; performance reviews and recommendation letters; clean code and code documentation; technical reports; progress reports; proposals; or recommendation reports. This course is recommended for students who plan to seek jobs in industry. Fulfills the Institute scientific writing requirement. For Winter and Spring terms, seniors will be given priority; however this class is open to all students in EAS and GPS, and to students in other divisions as space allows. Instructor: Meyer.

SEC 13. Written Communication about Engineering and Applied Science to Non-Specialists. *3 units (1-0-2); terms to be arranged.* Engineers and applied scientists often work on highly technical, specialized projects. However, their work is often of interest to readers with varied areas and levels of technical expertise, including investors, community stakeholders, government regulators, consumers, voters, students, and enthusiasts. This course introduces students to diverse types of writing about technical engineering and applied science topics intended for these "non-specialist" readers who lack some or all of the technical knowledge the author has. Students will compose multiple texts written for different purposes and to different types of audiences outside of their area of expertise. This course is recommended for students who may plan entrepreneurial, non-profit, or government careers, where communication to non-specialists is crucial to success. It may also interest students who enjoy public advocacy or creative writing about technical topics. Fulfills the Institute scientific writing requirement. For Winter and Spring terms, seniors will be given priority; however this

class is open to all students in EAS and GPS, and to students in other divisions as space allows. Instructor: Burkett.

SEC 100. Special Topics in Scientific and Engineering Communication. *Units to be arranged; terms to be arranged in consultation with the instructor.* Content may vary from year to year, at a level suitable for advanced undergraduate or graduate students. Topics will be chosen to meet the emerging needs of students. Instructor: Gold.

E/SEC 102. Scientific and Technology Entrepreneurship. *9 units (3-0-6);* For course description, see Engineering

E/SEC 103. Management of Technology. *9 units (3-0-6);* For course description, see Engineering

ChE/Ch/Bi/SEC 107. Social Media for Scientists. *9 units (3-0-6);* For course description, see Chemical Engineering

SEC 110. Technical Seminar Presentations. *3 units (3-0-0); terms to be arranged.* The purpose of this graduate-level course is to equip students with the skills, knowledge, and experience necessary to give effective oral presentations. The course will include a mix of formal instruction, group discussions, practice presentations, and individual feedback. Instructor: Gold.

SEC 111. Effective Communication Strategies for Engineers and Scientists. *6 units (3-0-3); third term.* This graduate course is designed to increase students' effectiveness in communicating complex technical information to diverse audiences and to deepen their understanding of key tools and techniques. Students will explore scientific storytelling through multiple genres, including oral presentations, written articles, and visual narratives. In-class workshops will provide students with the opportunity to revise their work and consider feedback from others. Each student will complete the class with a portfolio of projects highlighting various aspects of their communication skills. (Registration by application only, and EAS graduate students are given priority.). Instructor: Gold.

SEC 120. Data Visualization Projects. *6 units (2-0-4); third term.* This course will provide students with a forum for discussing and working through challenges of visualizing students' data using techniques and principles from graphic design, user experience design, and visual practices in science and engineering. Working together, we will help create and edit students' graphics and other visual forms of data to improve understanding. We will consider the strengths and weaknesses of communicating information visually in drawing, design and diagramming forms such as flow charts, brainstorming maps, graphs, illustrations, movies, animation, as well as public presentation materials, depending on the needs of students' projects. Our approach will be derived from design principles outlined by Edward Tufte and others. The course is targeted towards students across disciplines using visual

display and exploration in research. There is no pre-requisite, but students should be competent in acquiring and processing data. Not offered 2024-25.

SEC 130. Science Activation: Bringing Science to Society. *6 units (3-0-3); second term.* Working with policy makers is more than science communication. It requires a bilateral approach to exploring complex problems and solutions that encompass societal objectives as well as physical requirements. An intellectual understanding of the differences communication norms in the research and policy realms can help scientists make better decisions about how to communicate about their work and engage with policy makers to get it used. This course combines analysis of the differences in communication norms with practical experience in communicating and developing relationships with elected officials and their staffs. Not offered 2024-25.

SEC 201. Advancing Inclusion in College Teaching. *1 unit (1-0-0); second term.* In this weekly, discussion-based course, participants will explore concrete practices to advance inclusion and anti-racism as college-level STEM instructors, and discuss how they might implement these steps in their own teaching practice both at Caltech and beyond. Topics for discussion include establishing an inclusive learning environment, designing equity into syllabi and student assessments, and building anti-racist curricular materials, with additional topics to be guided by participant interests. This course aims to bring together an active community of teaching and learning practitioners for ongoing work and dialogue. There is a cap of 12 students for this course. Instructor: Imamura.

SOCIAL SCIENCE

SS 200. Selected Topics in Social Science. *Units to be determined by arrangement with instructors; offered by announcement.* Instructors: Staff, visiting lecturers.

SS 201 abc. Analytical Foundations of Social Science. *9 units (3-0-6); third term.* This course covers the fundamentals of experimental economics, used to study traditional questions (e.g., equilibration of supply and demand) and newer behavioral economics questions. We start with some early history of experimental economics. Methodological discussions include principles of randomization, internal validity, statistical power, between- and within-subject designs, generalizability, field experiments, and reproducibility. Applications include testing theories of risk and time preference, non-cooperative games, market trading, auctions, and AI. Open to Social Science graduate students only. Part a and b not offered 2025-26. . Instructor: Sprenger.

SS 202 abc. Political Theory. *9 units (3-0-6); first, second, third terms.* Course will introduce the student to the central problems of political

theory and analysis, beginning with the essential components of the democratic state and proceeding through a variety of empirical topics. These topics will include the analysis of electoral and legislative institutions, legislative agenda processes, voting behavior, comparative political economy, and cooperation and conflict in international politics. The student will be sensitized to the primary empirical problems of the discipline and trained in the most general applications of game theoretic reasoning to political science. Open to Social Science graduate students only. Instructors: Katz, Hirsch, Lopez-Moctezuma.

SS 205 abc. Foundations of Economics. *9 units (3-0-6); first, second, third terms.* This is a graduate course in the fundamentals of economics. Topics include comparative statics and maximization techniques, the neo-classical theory of consumption and production, general equilibrium theory and welfare economics, public goods and externalities, the economic consequences of asymmetric information and incomplete markets, and recursive methods with applications to labor eco-nomics and financial economics. Open to Social Science graduate students only. Instructors: Caradonna, Pomatto, Niemeyer.

SS 209. Behavioral Economics. *9 units (3-0-6); first term. Prerequisites: SS 201 abc or instructor's permission.* This course explores how psychological facts and constructs can be used to inform models of limits on rationality, willpower and greed, to expand the scope of economic analysis. Topics include overconfidence, heuristics for statistical judgment, loss-aversion, hyperbolic discounting, optimal firm behavior when consumers are limited in rationality, behavioral game theory, behavioral finance, neuroeconomic dual-self models, and legal and welfare implications of rationality limits. Not offered 2025-26.

SS 210 abc. Foundations of Political Economy. *9 units (3-0-6); second term. Prerequisites: SS 202 c, SS 205 b.* Mathematical theories of individual and social choice applied to problems of welfare economics and political decision making as well as to the construction of political economic processes consistent with stipulated ethical postulates, political platform formulation, the theory of political coalitions, and decision making in political organizations. Part a and c not offered 2025-26. Instructor: Gibilisco.

SS 211 abc. Advanced Economic Theory. *9 units (3-0-6); first, third terms.* May be repeated for credit. Advanced work in a specialized area of economic theory, with topics varying from year to year according to the interests of students. Instructors: Niemeyer, Tamuz.

SS 212 abc. Experimental Economics. *9 units (3-0-6); first, second, third terms. Prerequisites: SS 201 abc, SS 202 abc, SS 205 abc, SS 222 abc or with permission of the instructor.* This three-quarter sequence is designed for advanced Social Science Ph.D. students with the aim of introducing students to the methodology of modern experimental economics and to provide an in-depth overview of the contributions of experimental methods to a wide variety of fields. The specific topics

covered, which will vary from year to year, include but are not limited to individual decision making, preference and belief elicitation, game theory, social learning, bargaining, labor economics, public finance, auctions, voting and elections, competitive markets, networks, matching, mechanism design, coordination/communication, and information aggregation. The focus will be on theory-based experiments and how the dialog between theoretical analysis and laboratory data feeds each other, thereby leading to new avenues of theoretical and experimental research. Instructors: Nielsen, Agranov, Sprenger.

SS 213 abc. Financial Economics. *9 units (3-2-4); first term.* Mathematical finance: Pricing financial derivatives, risk management, and optimal portfolio selection. Methods of stochastic, Ito calculus for models driven by Brownian motion. Asset pricing theory: Mean-variance theory, information economics, continuous-time finance and differential equations, intertemporal consumption-based asset pricing theories, recent developments in intermediary-based and behavioral asset pricing theories. Behavioral finance: Empirical facts about asset prices, investor trading behavior, and firm behavior. Psychology about investor preferences and beliefs. Behavioral finance models that explain empirical facts. Trading strategies implemented by hedge funds. Prescriptive behavioral finance that aims at helping individuals and institutions to make better financial decisions. Not offered 2025-26.

SS/Ma 214. Mathematical Finance. *9 units (3-0-6); first term.* A course on pricing financial derivatives, risk management, optimal portfolio selection, financial markets equilibria, and optimal compensation of managers using mathematical models. Students will be introduced to methods of Stochastic, Ito Calculus for models driven by Brownian motion. Instructor: Cvitanic.

SS 218. Neuroscience Applications to Economics and Politics. *9 units (3-0-6); first term.* Topics in behavioral, affective, and social neuroscience that inform how individuals make economic decisions. Applications of neuroscience ideas and methods to understanding choice under risk and uncertainty, temporal discounting and self-control, advertisement and preference formation, habit, addiction, and judgment bias. Not offered 2025-26.

SS 222 abc. Econometrics. *9 units (3-0-6); first, second, third terms.* Introduction to the use of multivariate and nonlinear methods in the social sciences. Open to Social Science graduate students only. Instructors: Sherman, Xin, Sherman.

SS 223 abc. Topics in Theoretical and Applied Econometrics. *9 units (3-0-6); third term. Prerequisites: SS 222 abc; may be repeated for credit.* The courses in this sequence cover advanced methods and tools in econometrics, as well as their applications to a variety of topics in economics, including industrial organization, dynamic choice, information economics, political economy, market design, and behavioral economics. Part a and b not offered 2025-26. Instructor: Xin.

SS 224. Social Science Data. *9 units (3-3-3); first term.* This course provides broad coverage of empirical methods in the social sciences. This includes both methods of data collection and practical aspects of data analysis, as well as related issues of survey design, experimental design, techniques for handling large datasets, and issues specific to the collection and analysis of field and historical data. This course also provides students with hands-on experience with data. Open to Social Science graduate students only. Instructor: Alvarez.

SS 225. Experimetrics. *9 units (3-0-6); third term.* This course explores the interaction of experimental design and econometric inference in the laboratory approach to economic questions. The course critically evaluates existing experimental studies to highlight this interaction and motivate consideration of inferential strategies early in an experiments design. Methodological topics may include testing theories in two-by-two designs, power and optimal design, classifying subjects into canonical types, testing based on elicited preferences and beliefs, and challenges introduced by communication and dynamics in economic experiments. Not offered 2025-26.

SS 228 abc. Applied Empirical Methods in the Social Sciences. *9 units (3-0-6); third term.* Course covers methods used in contemporary applied empirical work in a variety of social sciences. Topics covered include (a) maximum likelihood, Bayesian estimation, management and computation of large datasets, (b) reduced form methods like instrumental variables (IV), difference-in-differences (DID), natural experiments, event study and panel data methods, and (c) structural estimation. Emphasis is on the application of tools to substantive social science problems rather than statistical theory, in areas including political science, political economy, corporate finance, and accounting. Application focus will vary with instructor interests. Part a and b not offered 2025-26. Instructor: Lopez-Moctezuma.

SS 229 abc. Theoretical and Quantitative Dimensions of Historical Development. *9 units (3-0-6); first, third terms.* May be repeated for credit. Introduction to modern quantitative history. The tools of economic and political theory applied to problems of economic, social, and political development in a historical context. Second and third terms will be graded together. A pass/fail will be assigned in the second term and then changed to the appropriate letter grade at the end of the third term. Instructors: Rosenthal, Janas.

SS 231 abc. American and Comparative Politics. *9 units (3-0-6); second term. Prerequisites: SS 202 abc, or permission of the instructor.* An advanced graduate Social Science sequence in American and comparative politics. The sequence will focus on political institutions and behavior, introducing students to the important theories of American and comparative politics. Students will learn how historical, observational, and experimental data are used in American and comparative political analysis. Section a offered by Katz; section b not offered 2025-26.

Instructor: Katz.

SS 281. Graduate Social Science Writing Seminar. *9 units (3-0-6); first term.* Only open to advanced graduate students in social science. How can social scientists write in a style that makes someone actually want to read their papers? This seminar combines writing exercises with help in planning a professional social science paper and with extensive comments on drafts. Instructor: Gibilisco.

SS 282 abc. Graduate Proseminar in Social Science. *3 units (1.5-0-1.5); first, second, third terms.* Course for graduate students in social sciences. Students present their research and lead discussion of material relevant to their research program. Open to Social Science Graduate Students only. Instructors: Druckenmiller, Nielsen.

SS/Psy/CNS 285. Topics in Social, Cognitive, and Decision Sciences. *3 units (1.5-0-1.5); first term.* The goal of this course is to introduce graduate students to current research questions in cognitive sciences, political science, and economics. Select faculty will present their research background, methods, and a sampling of current studies. Background readings and pdf of presentation will be provided. Instructor: Sprenger.

SS 299. Writing. *9 units (3-0-6); second term.* This course is designed for students to improve their ability for written expression in the English language. This course is only open to graduate students in the Social Decision Neuroscience and Social Science Ph.D. programs. Instructor: Sherazi.

SS 300. Research in Social Science. *Units to be arranged;*

STUDENT ACTIVITIES

SA 15 abc. Student Publications. *SA 15 a 5 units (2-0-3), first term; SA 15 bc 4 units (1-0-3), second and third terms; first, second, third terms. Prerequisites: SA 15 a is a prerequisite for SA 15 b and SA 15 c.* This course will enable students to produce quality, journalistically-crafted stories for the Tech newspaper. It will teach journalistic values of clarity, accuracy, fairness and balance, and acquaint the students with the primary elements of journalism, including reporting, basic story structure and news/opinion-writing distinctions. Students will produce feature stories for the Tech (with assigned art or graphics) about campus life and activities, profiles of campus faculty or staff, and issues of campus community interest. May be re-taken for credit. Not offered 2022-23. Instructor: Kipling.

SA 16 abc. Cooking Basics. *3 units (0-3-0); first, second, third terms.* The class will survey different cooking styles, techniques, and cuisines from around the world. Topics covered may include knives and tools;

tastes and flavors; sauces and reductions; legumes, grains, and beans; meat; dessert. The emphasis will be on presentation and creativity. Instructor: Staff.

SA 42. Computer Science Education in K-14 Settings Practicum. *4 units (0-2-2); first, second, third terms. Prerequisites: CS 42.* This course is a follow-on for students who have already taken CS 42 and would like to continue as part of a teaching group partnered with a local school or community college. Each week students are expected to spend about 2 hours teaching and 2 hours developing curricula. Students may take SA 42 multiple times. Graded pass/fail only. Instructor: Ralph.

SA 59. Special Topics. *Units to be arranged; offered by announcement.* The topics covered vary from year to year, depending on the students and instructor. For undergraduate students. Graded pass/fail. May be re-taken for credit. Instructor: Faculty or Staff.

SA 80 abc. Health Advocates. *3 units (1-1-1); first, second, third terms.* A course designed to involve students with health care and education, develop familiarity with common college health problems, and provide peer health services on and off campus. The training involves American Red Cross Emergency Medical Response certification, routine illnesses and injuries and peer counseling. All training is cumulative from the prior term. Opportunities to volunteer at community first aid stations are provided. Instructor: Stapf.

SA 81. Peer Advocates. *3 units (1-1-1); third term.* A course designed to involve students with appropriate peer support and education, develop familiarity with common college mental health problems, and provide peer mental health support to students on and off campus. Active listening skills, identifying students in distress, suicide prevention, lectures and discussions on substance abuse, dating violence, sexual assault, depression, and other relevant mental health topics, as well as ongoing consultation about practical experience. Enrolled with permission only. Instructor: Staff.

SA 82. Building Effective Habits and Routines. *3 units (1-0-2); third term.* This course empowers students to enhance their well-being and academic success through their habits and routines. Students will explore essential topics including stress management, time optimization, and sleep hygiene, and develop personalized strategies to achieve their goals. Instructor: Staff.

VISUAL CULTURE

Hum/VC 48. Ways of Seeing. *9 units (3-0-6);* For course description, see Humanities

Hum/VC 49. Seeing Race. *9 units (3-0-6);* For course description, see Humanities

Hum/VC 50. Introduction to Film. *9 units (3-0-6);* For course description, see Humanities

Hum/VC 51. Icons and Iconoclasm. *9 units (3-0-6);* For course description, see Humanities

Hum/VC 52. Color. *9 units (3-0-6);* For course description, see Humanities

VC 60. Art/Media. *Units to be determined by the instructor; offered by announcement.* A practice-based course taught by a visiting artist in residence. See registrar's announcement for details.

VC 61. Environmental Justice. *6 units (2-0-4); first term.* This seminar course will explore and discuss the unique intersection of environmental racism, environmental justice, and academia. Course material will primarily feature readings and videos on a case study-like basis and focus on bringing conversations typically had in humanities, social sciences and activism to the bio and geosciences. Topics will center around two primary approaches: an "outward-facing" component that looks at environmental racism through the lens of various activisms, and an "inward-facing" component addressing the biases/malpractices broadly employed in the biological and geosciences, as well as the apparent moral dilemmas of decisions involving multiple stakeholders. Out of class work will largely be based on assigned readings, some multimedia presentations, and occasional writings and thought exercises. This course is taught concurrently with Ge/ESE/Bi 248 and can only be taken once, as VC 61 or Ge/ESE/Bi 248. Not offered 2025-26. .

VC 70. Traditions of Japanese Art. *9 units (3-0-6); third term.* An introduction to the great traditions of Japanese art from prehistory through the Meiji Restoration (1868-1912). Students will examine major achievements of sculpture, painting, temple architecture, and ceramics as representations of each artistic tradition, whether native or adapted from foreign sources. Fundamental problems of style and form will be discussed, but aesthetic analysis will always take place within the conditions created by the culture. Not offered 2025-26.

VC 73. Seeing Systems: Critical Research as Visual Art. *9 units (3-0-6); first.* Since the 1960s, artists have increasingly used visual art to question the very foundation of the world we live in. Through site-specific research and visual projects, this course will teach students how to use the practice of visual art to raise big questions about our world and how its systems (political, economic, technological, etc.) do or do not serve our best interests. Students will be introduced to the work of conceptual artists such as Trevor Paglen, Forensic Architecture, Carolyn Lazard, and Park MacArthur, who examine technological,

political and economic themes through research in order to produce meaningful installations. Students will participate in a combination of research, critical thinking, visual art making, group critiques, and visiting exhibitions of contemporary artists working in the field today. Previous art or art history experience is encouraged but not required. Not offered 2025-26. .

VC 74. Imaging Ecological Futures: Visual Art and Ecology. *9 units (3-0-6); third.* How can art help visualize a post-carbon future? This class will look at environmental art projects over the past 50 years, from the birth of ecofeminism and anti-nuclear movements to today's artistic approaches to environmental justice. This class will research and discuss the legacy of eco artists, read seminal works, and engage in class discussions drawn from contemporary writing on the politics of colonial landscapes and queer approaches to ecology. These artworks address issues of sustainability, extraction and marginalization that affect vulnerable human bodies and the non-human world. We will then use ecological and feminist methods to create personal artworks. This class will use the resources of the Huntington Botanical Garden, and potentially field trips for plein air works on major local energy infrastructure sites. Not offered 2025-26. .

VC/E 81. Careers in STEAM. *1 unit (1-0-0); second term.* A series of weekly seminars by practitioners in industry and academia working at the intersections of science, technology, engineering, art and design. The course can be used to learn more about the different careers in these interdisciplinary areas. Guest speakers will talk about their career trajectory, the nature of their work and the role that science, engineering and/or computing plays in their field. Speakers may include professionals in the fields of investigative science journalism, film/TV, apparel design and manufacturing, architecture, music/sound engineering and editing, art, culture and heritage exhibition and conservation, creative coding, technological art and other areas. Topics will be presented at an informal, introductory level. Graded pass/fail. Not offered 2025-26.

E/VC 88. Critical Making. *9 units (3-0-6);* For course description, see Engineering

E/H/VC 89. New Media Arts in the 20th and 21st Centuries. *9 units (3-0-6);* For course description, see Engineering

VC 90. Reading in Visual Culture. *9 units (1-0-8); first, second, third terms. Prerequisites: Instructor's permission.* An individual program of directed reading in Visual Culture, in areas not covered by regular courses. VC 90 is intended primarily for Visual Culture minors. Interested students should confer with a Visual Culture faculty member and agree upon a topic before registering for the course. Instructors: Faculty, Staff.

VC/H 102. Looking East/Looking West. *9 units (3-0-6); third term.* From teapots to pastries, photographs to palanquins, objects and images

mediated encounters between people and helped define the "Orient" and the "Occident". This class looks at the visual and material culture produced by and consumed during encounters between European and Asian travelers, diplomats, artists, writers, and tourists since the eighteenth century. Not offered 2025-26.

L/VC 109. Introduction to 20th-Century French Cinema. *9 units (3-0-6);* For course description, see Languages

En/VC 110. Sinners, Saints, and Sexuality in Premodern Literature. *9 units (3-0-6);* For course description, see English

L/VC 111. Introduction to 21st-Century French Cinema. *9 units (3-0-6);* For course description, see Languages

En/VC 116. Picturing the Universe. *9 units (3-0-6);* For course description, see English

En/VC 117. The New York School of Poets. *9 units (3-0-6);* For course description, see English

VC 120. Landscape, Representation and Society. *6 units (2-2-2); third term.* This course examines historical and contemporary representations of the natural world in art and science through a social lens. We will draw upon theory and practices from art, science, geography and landscape studies to critically analyze how artists, explorers, speculators, scientists, military strategists, and local inhabitants use environmental imagery for diverse purposes with sometimes conflicting interests. The course includes projects, lectures, readings, discussions and a 2-day field trip. Students will learn to think critically while developing creative, culturally complex approaches to observing, recording and representing the natural world. Students hoping to combine their course work with a research paper may sign up for a separate independent study and conduct research concurrently, with instructor approval. Not offered 2025-26.

En/VC 129. Literature/Photography/Facticity. *9 units (3-0-6);* For course description, see English

VC 130. Surveillance. *9 units (3-0-6); third term.* This course examines surveillance, one of the defining features of twenty-first-century life, with wide-ranging implications (from intelligence gathering and biometrics to social media and contemporary art), and a key point of intersection between modern technology and visual culture. Though it applies more broadly, the concept of "surveillance," from the Latin vigilare ("to watch") and the French surveiller ("to watch over"), originated in practices of looking and observation that still define many of its most significant practices today. Building on these etymological roots, we will treat surveillance as, first and foremost, a visual practice and survey the longer history of surveillance (and counter-surveillance) techniques as well as the theories that have emerged to describe its social effects,

moral and ethical stakes, and changing legal status. Instructor: Jacobson.

VC 131. Visual Culture and the California Environment. *9 units (3-2-4); third term.* This course examines historical and contemporary visual representations of the natural world and resources in art and science through a political, economic and social lens. We will draw upon theory and practices from art, science, geography and landscape studies to critically analyze how artists, scientists, corporations, government agencies, activists, and local inhabitants use environmental imagery for diverse purposes with sometimes conflicting interests. Each term will center on a specific theme related to California and climate change, for example, water or energy. The course includes projects, lectures, readings, discussions and a 2-day field trip. Students will learn to think critically while developing creative, culturally complex approaches to observing, recording, and representing the natural world. Instructors: Jacobson, Mushkin.

En/VC 135. Dickens's London. *9 units (3-0-6);* For course description, see English

L/VC 153. Refugees and Migrants' Visual and Textual Representations. *9 units (3-0-6);* For course description, see Languages

En/VC 160 ab. Classical Hollywood Cinema. *9 units (3-0-6);* For course description, see English

En/VC 161. The New Hollywood. *9 units (3-0-6);* For course description, see English

VC 162. Data, Algorithms and Society. *9 units (3-0-6); third term.* This course examines algorithms and data practices in fields such as machine learning, privacy, and communication networks through a social lens. We will draw upon theory and practices from art, media, computer science and technology studies to critically analyze algorithms and their implementations within society. The course includes projects, lectures, readings, and discussions. Students will learn mathematical formalisms, critical thinking and creative problem solving to connect algorithms to their practical implementations within social, cultural, economic, legal and political contexts. Enrollment by application. Taught concurrently with CS/IDS 162 and can only be taken once as VC 172 or CS/IDS 162. Instructors: Mushkin, Ralph.

VC 169. The Arts of Dynastic China. *9 units (3-0-6); first term.* A survey of the development of Chinese art in which the major achievements in architecture, sculpture, painting, calligraphy, and ceramics will be studied in their cultural contexts from prehistory through the Manchu domination of the Qing Dynasty (1644-1911). Emphasis will be placed on the aesthetic appreciation of Chinese art as molded by the philosophies, religions, and history of China. Instructor: Wolfgram.

VC 170. Special Topics in Visual Culture. *9 units (3-0-6); offered by announcement.* An advanced humanities course on a special topic in visual culture. Topics may include art history, film, digital and print media, architecture, photography or cartography. It is usually taught by new or visiting faculty. The course may be re-taken for credit except as noted in the course announcement. Limited to 15 students. See registrar's announcement for details. Instructor: Staff.

VC 171. Arts of Buddhism. *9 units (3-0-6); third term.* An examination of the impact of Buddhism on the arts and cultures of India, Southeast Asia, China, Korea, and Japan from its earliest imagery in the 4th century B.C.E. India through various doctrinal transformations to the Zen revival of 18th-century Japan. Select monuments of Buddhist art, including architecture, painting, sculpture, and ritual objects, will serve as focal points for discussions on their aesthetic principles and for explorations into the religious, social, and cultural contexts that underlie their creation. Not offered 2025-26.

En/VC 172. Heritage and Its Discontents. *9 units (3-0-6);* For course description, see English

VC 175. The Art of Science. *9 units (3-0-6); second term.* This course examines the frequent and significant encounters between what chemist/novelist C.P. Snow famously dubbed the "two cultures"-the sciences and the humanities-with an emphasis on forms and practices of visual culture that blur the boundaries between science, technology, and art. What role, we will ask, have visual culture and visuality played in the construction of scientific knowledge? Taking a broad historical and geographical approach, we will explore topics including representations of science and technology in the arts and popular culture; the use of photography, illustration, and visualization in the sciences; histories of visuality and visual devices; and the everyday visual practices of scientific inquiry. Not offered 2025-26.

VC 176. Representation Matters?. *9 units (3-0-6); first term.* Organizations from Google to NASA are recruiting diversity task teams. College DEI initiatives have become a flashpoint in the culture wars. Social media feeds are flooded with clickbait headlines like "13 Queer Superheroes We Need to See" and "Disney's Ariel is Black and People are MAD!" Everywhere, debates about equity and transformation seem to turn on a single phrase: "Representation matters!" But how does representation matter, why does it matter, and when did it come to matter most? Pushing beyond competing narratives of 'wokeness' and 'inclusion', this course thinks through representation as a uniquely visual formula for social change with its own history, assumptions, and limitations. Working at nested scales from national controversies (like an all-female Ghostbusters) to local case studies (like East Hollywood's Flavors From Afar, with its roster of refugee chefs), students will study efforts to increase visibility and institutionalize diversity across cultural contexts, and explore how communities, in turn, challenge and transform identities prescribed for them. Not offered 2025-26. .

VC 177. Other Photographies. *9 units (3-0-6); third term.* Histories of photography typically begin with the invention of the camera in 19th century France, highlighting the key figures, movements, and themes of a Western art form. At best, the Global South is an addendum to this narrative - a place photography happens to, rather than a site of visual innovation. Taking an alternative approach to the canon, this course centers non-Western image cultures in the history and theorization of the medium, following the camera as it travels from the studios of colonial bureaucrats in Rajasthan through the struggle against South African apartheid to Tunisia's smartphone revolution. Adopting a global and comparative lens, students will read classic works of photographic theory alongside anticolonial philosophy, fiction, and art manifestos, exploring how a familiar medium has been repeatedly re-imagined and re-invented to suit new contexts and meet new needs. Ultimately, we'll ask how widening our field of view can expand our understanding of photography, shifting how we read images more broadly. Not offered 2025-26. .

VC 178. Extraction! Art, Architecture, & Environmental History. *9 units (3-0-6); third term.* What is art and architecture? What is the environment? This seminar will explore the intersection of the environment with art and architecture from a material point of view, charting their entangled relationship from the age of exploration to the dawn of the Anthropocene, ca. 16th-19th c. In addition to examining how the environment has inspired (and challenged) art and architecture, we will especially focus on the raw and critical resources that made art and architecture possible: tracing a material's journey from its literal roots in a garden to its extraction, production, trade, materials science, and use in art and architecture. We will also consider the ecological aftermath of these processes, learning to interrogate what underpins visual culture's beauty: from environmental impact, toxicity, global politics, colonialization, enslaved labor, and the economy. This class will have on-site visits to the Huntington Museum, Library, and Botanical Gardens. Instructor: Linden.

H/HPS/VC 185. Angels and Monsters: Cosmology, Anthropology, and the Ends of the World. *9 units (3-0-6);* For course description, see History

H/HPS/VC 186. From Plato to Pluto: Maps, Exploration and Culture from Antiquity to the Present. *9 units (3-0-6);* For course description, see History

En/VC 197. The Urban Environmental Imagination. *9 units (3-0-6);* For course description, see English

En/VC 198. Graphic Non-Fiction: Memoir, History, and Journalism. *9 units (3-0-6);* For course description, see English

En/VC 199. Shakespeare at the Cinema. *9 units (3-0-6);* For course description, see English

WRITING

Wr 2. Introduction to Academic Writing. *9 units (3-0-6); first term.* This course offers a focused introduction to the practices of reading, thinking, and writing that characterize academic writing. More specifically, the course teaches students how to articulate a position, situate writing within specific contexts, engage with the work of others, locate and provide convincing evidence, and understand the expectations of different types of academic readers. Students will take several writing projects through multiple stages of revision, improving their work with feedback from seminar discussions, workshops, and frequent one-to-one conferences with the instructor. Students are placed in Wr 2 based on a writing assessment that is required of all incoming students; successful completion of the course is required before taking first-year humanities courses. Enrolled students may be required to take Wr 3, 4, and/or 50 in subsequent quarters. Instructors: Hall, Manoukian, Schneiderman, Sherazi.

Wr 3. Reading and Composing Academic Writing. *9 units (1-0-8); Offered by announcement.* This course builds on Wr 1 or 2 for students who need additional instruction in both the core concepts and practices of academic writing before beginning their first-year humanities coursework. The course will focus on developing critical reading skills and composing successful academic essays. By taking several writing projects through multiple stages of revision, students will develop a deeper sense of their strengths and limitations as writers, and seminar discussions, workshops, and frequent one-to-one conferences with the instructor will equip students to address those limitations. Not available for credit toward the humanities-social science requirement. Enrolled students may be required to take Wr 4 and/or 50 in subsequent quarters. Instructor: Staff.

Wr 4. Principles and Practices of Academic Writing. *3 units (1-0-2); second term.* This course follows Writing 2 and offers an opportunity for more focused study and discussion of core concepts in academic writing, such as audience, genre, argument, working with sources, and process. Weekly readings offer concrete guidance on these topics, and class discussions expand on that guidance, providing insights into common challenges college writers encounter. Not available for credit toward the humanities-social science requirement. Instructor: Hall.

Wr 50. Tutorial in Writing. *1 unit; first, second, third terms.* By permission only. Individualized tutorial instruction in writing and communication for students who benefit from weekly discussions about their work as writers. Not available for credit toward the humanities-social science requirement. Instructor: Hall.

En/Wr 83. Personal Narrative and STEM Research. *9 units (3-0-6);* For course description, see English

En/Wr 84. Communicating Science to Non-Experts. *9 units (3-0-6);* For course description, see English

ESL/Wr 107. Fundamentals of Scientific Writing. *6 units (3-0-3);* For course description, see English as a Second Language

Wr 109. Writing and Publishing Research Articles in STEM Fields. *6 units (3-0-3); summer term.* This course focuses on strategies for composing an academic journal article in a STEM field. The rhetorical purpose and form of each section of the journal article will be considered in depth. The course is intended for graduate students who are prepared to be a lead author on a manuscript. While the course will cover strategies for collaborative writing, students will be asked to draft sections of an original journal article based upon their own research. The course will also provide guidance for preparing a manuscript for submission and responding to feedback from peer reviewers. Clarity in scientific writing and creating effective figures will also be discussed. Course enrollment is limited to 15 students. Not offered 2025-26.

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