

Information for Undergraduates



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 FRESHMAN CLASS

Students are admitted to the freshman class on the basis of strong academic performance in a rigorous course of college preparatory study, especially in the areas of math and science; results of the SAT or ACT, and one SAT science subject test and the SAT mathematics level 2 test; teacher and counselor evaluations; personal characteristics; a demonstrated interest in math, science, or engineering; and information provided on the application.

APPLYING

Information on the application process can be found on the admissions office website at www.admissions.caltech.edu. Students are encouraged to apply online through the Common Application, the Coalition 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 freshman class must be submitted online by November 1 for Early Action or January 3 for Regular Decision.

EARLY ACTION

The Early Action application process requires that the completed application be submitted online by November 1. Under this application plan, students will be notified in mid-December of the admission decision. Students admitted under Early Action have until May 1 to make their commitment to attend.

HIGH SCHOOL REQUIREMENTS

Students are expected to prepare for Caltech by successfully completing the following curriculum:

- Four years of mathematics (including calculus)
- One year of physics
- One year of chemistry
- Three years of English (four years recommended)
- One year of U.S. history/government (waived for international students)

Standardized Exams

Applicants are required to take the following standardized tests by the October test series for Early Action consideration, and by the December test series for Regular Decision consideration:

SAT or ACT

SAT Mathematics Level 2

One of the following SAT subject tests: Biology (molecular or ecological), Chemistry, or Physics

TOEFL (for international applicants)

Information regarding the College Board examinations can be found online at www.collegeboard.org, or by contacting the College Board, 250 Vesey Street, New York, NY 10218; (212) 713-8000. For ACT, 500 ACT Drive, P.O. Box 168, Iowa City, IA 52243-0168; (319) 337-1270; www.act.org.

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.

Evaluations

Two teacher evaluations and a Secondary School Report are required. One evaluation must be from a math or science teacher, and one evaluation from a humanities or social science teacher (see the instructions in the application). A Secondary School Report must be filled out by the applicant's high-school counselor or other school official.

Additional Material

Descriptions of research projects and hands-on science and engineering experience are helpful, as is material that demonstrates experiences outside math and science. Additional material should be identified with name and date of birth.

Acceptance

Caltech is a National Association for College Admissions Counseling member and therefore agrees to comply with the candidate's reply date of May 1. Places in the entering class will not be held after May 1. Early Action applicants will be informed of their status in mid-December, and Regular Decision applicants will be informed by mid-March.

Deferral of Entrance

For reasons of travel or work, Caltech will consider requests from admitted students for a one-year deferral of entrance. Students who request a deferment must submit a written request stating the purpose of postponement.

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 are considered to have met the core requirement of Bi 1.

Chemistry

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. 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 (freshmen and transfers) will take a placement assessment to determine whether they are adequately prepared for the substantial writing component that is part of all freshman 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 freshman 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 freshman year, entering freshmen are asked to take a diagnostic exam 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; and if they are interested in advanced placement, they may also take an examination to determine whether they will begin the mathematics core sequence at an advanced level.

Normally, an entering freshman 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 freshman physics course, Ph 1 abc, is considerably more rigorous than most advanced placement work, and entering freshmen are encouraged to take Ph 1. A test is administered during the summer to aid in the organization of Ph 1; students who have performed particularly well can discuss the possibilities for advanced placement with the physics representative during orientation. A second test may then be required.

Residency Expectation

Freshman students have long been required to live on campus in undergraduate housing for their first academic year. With the opening of the Bechtel Residence, the residential experience is now extended to a full four years for undergraduate students, beginning with the class of 2022 (that is, freshmen matriculating in 2018). Undergraduate housing includes the eight houses (Avery, Blacker, Dabney, Fleming, Lloyd, Page, Ricketts, Ruddock), and the Bechtel Residence and Marks House and Braun House. Requests for exceptions from a four-year residency expectation should be submitted to the Office of Residential Experience, and must be approved by the Dean of Undergraduate Students and the Vice President for Student Affairs.

New Student Orientation

All freshmen, transfer, 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 help 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.

Freshman courses:

- Mathematics 1 abc
- Physics 1 abc
- Chemistry 1 ab
- Chemistry 3 a or 3 x
- Biology 1, 1 x, 8, or 9
- Humanities and Social Science electives
- Menu science class (see page 234; can be taken freshman 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. The Test of English as a Foreign Language (TOEFL) is required of transfer applicants whose native language is not English and who have not school instruction in English for two years or more. The TOEFL should be taken no later than the February test date.

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. Further instructions are included with the Caltech Transfer Application.

Transfer of Credit

The courses for which transfer applicants will receive credit, and the corresponding class standing, will be determined at the time of enrollment. The transfer applicant will submit course descriptions, syllabi, and final transcripts to the Registrar who will present the material to the faculty for evaluation.

Faculty members review each course submitted for credit on an individual basis. It is sometimes not possible, therefore, to answer questions regarding the acceptability of course work taken elsewhere. Before the student is admitted, transfer students will work through Admissions to obtain a pre-evaluation estimate. If the standard of work taken elsewhere is uncertain, additional examinations may be required before the question of credit is finally determined.

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 September 1. Completed applications should be received by the Office of Undergraduate Admissions by February 15. 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 www.admissions.caltech.edu. Students should apply online through the Coalition Application. For further information on admission, please call (626) 395-6341 or 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 violence 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 TitleIX@caltech.edu 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 www.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. Freshmen at Caltech ordinarily cannot participate in this exchange.

STUDY ABROAD AND STUDY 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 his or her 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 www.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 corresponds 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 PROGRAMS

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 room, board, 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 www.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 room 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 board 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 room charge, all students pay standard board and tuition, but should budget additional funds for food due to the length of the semester. Note that while students pay Caltech board fees, the board 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 technolo-

gy 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.

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. Note that the winter and spring terms can only be attended in years that do not overlap with Caltech term dates and only with the permission of École Polytechnique and Caltech. In addition, seniors may not attend the spring term if they plan to graduate in June.

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 *approndissement*. 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 room, board, 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. Further information, including application procedures and exact deadline dates, is available from the Fellowships Advising and Study Abroad Office: 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.

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 room, board, tuition, and other standard Caltech fees for the term. There is a supplemental charge for housing/board due to the lon-

ger 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 3.4 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.

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.

Students pay Caltech room, board, 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 Fellowships Advising and Study Abroad Office.

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 freshmen 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 www.usc.edu/afrotc. No military commitment is incurred until entering the junior year of the program or receipt of a scholarship after the freshman 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 \$1200. 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. The Institute can place a hold on a student's registration in a variety of circumstances including any failure to comply with Institute requirements.

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.

CHANGES IN REGISTRATION

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 he or she does not either complete satisfactorily or drop. A course is considered dropped when a drop card is completed and returned to the Registrar's Office. A student may not at any time withdraw from a course that is required for graduation in his or her 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. Registration for added courses is complete when an add card, signed by the instructor and the student's adviser, has been filed in the Registrar's Office. No credit will be given for a course for which a student has not properly registered. The responsibility for submitting drop cards and add cards to the Registrar's Office before the deadlines for dropping or adding courses each term rests entirely with 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.

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 freshmen advisers, and later option advisers, who will guide students to resources about the curriculum, graduation requirements, and Institute policies and procedures. Through the academic advising experiences at Caltech, students will develop an educational plan for successfully achiev-

ing their goals and select courses each quarter to progress toward fulfilling that educational plan. Undergraduate students are required to meet with their adviser at least once a year. 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 his or her 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

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 leave form. International students should consult with the International Student Programs Office regarding visa implications prior to submitting the leave petition.

The dean or designee 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.

A student on personal leave may not attend classes, live in Institute housing, participate in Institute programs, use Institute facilities, work on campus, or use student services such as the Health and Counseling Services, Center for Diversity, Career Services, or the Hixon Writing Center during the leave, unless approved in writing by the dean or designee.

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.

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 leave form. The dean or designee may grant a leave for medical reasons, provided the petition is recommended by the director of Health and Counseling Services or designee. 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 must provide documentation of the need for the leave by a licensed treatment provider. 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.

A petition to return from medical leave must be submitted six (6) weeks before the first day of the term for which the student intends to return. The return process includes an interview with the director of Health and Counseling Services and the submission of a completed return from medical leave and provider recommendation forms. Students are expected to sign a release of information form authorizing their treatment providers to communicate with Caltech, including representatives of Health and Counseling Services and the Dean's office to determine readiness to return and recommendations for reasonable accommodations. 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. Additional information and resources regarding medical leave, including financial and transcript implications, can be found at deans.caltech.edu.

While on Medical 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. A student on medical leave may not attend classes, live in Institute housing, participate in Institute programs, use Institute facilities, work on campus, or use student services such as Health and Counseling Services, Center for Diversity, Career Services or the Hixon Writing Center during the leave, unless approved in writing by the dean or designee.

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 petition and to the Office of Undergraduate Students after obtaining a recommendation from the director of Health and Counseling 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 to the Office of Undergraduate Students 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

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, 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 Health and Counseling Services, or designee, 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.

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 on involuntary leave may not attend classes, live in Institute housing, participate in Institute programs, use Institute facilities, work on campus, or use student services such as Health and Counseling Services, Center for Diversity, Career Services or the Hixon Writing Center during the leave, unless approved in writing by the dean or designee.

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.

Withdrawal from the Institute

Formal separation from the Institute is effected by filing a completed undergraduate leave form in the dean of students office to be forwarded to the registrar and other appropriate offices. The effective date of a withdrawal is entered by the 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. Return from involuntary leave requires approval through the dean of students office. Reinstatement rules are listed under scholastic requirements. 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.

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. Freshmen are not held to the 1.9 GPA requirement during the first two terms when all courses are taken pass/fail. 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. 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.

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.

DEPARTMENTAL AND OPTION REGULATIONS

Selection of Option

By the middle of the third term, freshmen 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 freshman 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 designat-

ed 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 his or her choice provided he or she has (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 he or she has 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 a four-year residential experience (study abroad included) in which students have the time to explore their academic interests in a deep and rigor-

ous 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 residence 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 he or she expects 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 his or her 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 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 freshmen 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 his or her adviser and the Dean or Associate Dean of Undergraduate Students. Petitions for overloads will not be accepted later than the last day for adding classes in any term.

An underload is registration for fewer than 36 units. Underload petitions for freshmen, 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. 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 pages 202-203. For more information about impact to aid, see page 220.

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 his or her 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 cours-

es 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.

UNDERGRADUATE EXPENSES

For freshmen 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.

EXPENSE SUMMARY 2019-2020

General:

General deposit.....	\$100.00 ¹
Orientation fee.....	\$500.00 ¹
Tuition.....	<u>\$52,506.00</u>
	\$53,106.00

¹This charge is made only once during residence at the Institute.

Other:

Student fees.....	\$2,094.00
Room (contract price).....	\$9,615.00 ²
Board (5 days / week).....	\$7,029.00
Books and supplies (est.).....	\$1,428.00
Personal expenses (est.).....	\$2,091.00

² The housing/room rate is calculated based on the weighted average of all available undergraduate on-campus housing options.

The tuition and fees charge for all students is payable in full before the first day of classes unless the student enrolls in the Direct Cost Three Payment Plan through the Bursar's Office. The fee to enroll in the plan is \$25.00 per term. Enrollment in the Direct Cost Three Payment Plan must be completed by August 12, 2019. Fees are subject to change at the discretion of the Institute.

Tuition for the baccalaureate degree is based on four years (12 terms) of residence regardless of unit load each term or if a student completes graduation requirements a term(s) early. The 12 term residence 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 residential requirement, entering students should expect to be in residence 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.

REFUNDS AND FEES

Refunds and Repayments

For all students, the institutional charges, e.g., tuition and room and board, 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.

Determining the Student's Last Date of Attendance or Withdrawal Date

The Office of the Registrar 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 official notification to the registrar (written or oral) of his or her 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
- academic counseling session
- academic advisement session
- turning in a class assignment

Determining the Return of Federal Funds

The Financial Aid Office and/or the Graduate 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, as well as Caltech and/or state grants or aid.

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, he or she 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 and/or the Graduate Office (as appropriate) 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 Perkins Loan Program
4. Federal Direct PLUS Loan Program
5. Federal Pell Grant Program
6. Federal SEOG Program
7. 7. Other Title IV programs

Any remaining refund will be returned to the other state, institutional, or private student assistance utilized. Federal Work Study is not included in any of these calculations.

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 page 197. Information regarding financial aid and underloads can be found on page 202, Part Time Enrollments (Underloads.)

For those undergraduate students who are eligible for underloading after completing 12 terms or by approved medical exception (page 197), the tuition will be charged as of Add Day at an AY2019-2020 rate of \$486.00 per unit plus \$698.00 for student fees per term, with a minimum ten unit charge of \$5,558.00 per term.

Dropping a Course

Students who are not enrolled full-time as of the last day to add courses will have their aid revised. Generally, students enrolling less than three-fourths time will have an increased work award. Additional information is available in the Financial Aid Office. For more information about impact to aid, see page 220, Underloads and Financial Aid.

Refund upon Withdrawal

When a student, for whatever reason, withdraws from Caltech during an academic term, a refund of tuition as well as room and board, 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 his or her 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 room and board 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 on page 201.

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.

General Deposit

Each new student is required at his or her first registration to make a general deposit of \$100, to cover possible loss and/or damage of Institute property. 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.

Fees for Late Registration

Registration is not complete until the student has enrolled in a program approved by his or her 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.

Fees for Late Payment

A \$50 late penalty may be charged by the Bursar's Office for failure to clear a past-due account at the beginning of instruction.

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.

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 students have paid their bill

at the Bursar's Office. Official transcripts and 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 he or she 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.

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, including those whose financial circumstances change during the year.

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, room and board, an allowance for meals not covered in the board contract, 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 of two round-trips from a student's home during the academic year, and a travel allowance based on airfare for two round-trips. 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 low-interest 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.

Students should not wait to be accepted for admission to Caltech before applying for financial aid. With the exception of international students, 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. (For information on non-need-based scholarships and prizes, starting on page 221.)

All students who believe they will need assistance to attend

Caltech are encouraged to submit financial aid applications. 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 2018-19	Hard Deadline
Fall Term	November 22, 2019
Winter Term	February 28, 2020
Spring Term	May 22, 2020

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 www.finaid.caltech.edu.

HOW TO APPLY FOR FINANCIAL AID

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 www.finaid.caltech.edu.

International Applicants

If you are applying for admission as a freshman for the fall of 2019 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 www.finaid.caltech.edu for instructions for applying for financial aid. International applicants who do not apply for financial aid by published deadlines, or who are denied aid for their first year at Caltech, are not eligible for need-based financial aid for any other academic period while they are undergraduates at the Institute (with the exception of citizens of Canada and Mexico). Those with financial aid offers will be eligible to apply for assistance in subsequent years. All eligible students must reapply for aid each year.

International students are required to complete the CSS/Financial Aid PROFILE. This online application has been modified to collect family income and asset information from international

students. Students will need to register for the PROFILE service online at www.collegeboard.com by December 15, 2019, and indicate the college(s) to which they will be applying. (Students can also visit EducationUSA Advising Centers, which are located around the world, to register online.) Students will then receive a personalized PROFILE application at www.collegeboard.com that should be completed and submitted by February 1, 2020. Please refer to the complete application instructions provided on the Caltech Financial Aid Office website at www.finaid.caltech.edu.

TYPES OF AID AVAILABLE

There are three basic categories of financial aid that may be awarded.

1. Grants and scholarships represent "gift aid," which does not need to be repaid. In general, a Caltech scholarship is awarded based on financial need. Caltech named and/or endowed scholarships are considered to be based on need and merit. If you qualify for a state or federal grant, this grant would be included in your financial aid package.
2. Federal Work-Study or Caltech Work-Study represents student employment funds that have been allocated for you to earn during the academic year. Summer Caltech Work-Study represents funds that have been allocated for you to earn during the summer. While a work-study award is not a guarantee of employment, Caltech generally has more opportunities for student employment than it has students interested in working.
3. Low-interest educational loans: Students are generally offered Caltech/Institute loans. Students may be awarded Federal Direct Stafford Loans if they request them.

CALTECH SCHOLARSHIPS

Awarded to students with demonstrated financial need. Recipients are expected to be enrolled full-time. The named and/or endowed scholarships are also need-based, but many have a merit component. Recipients of named and/or endowed scholarships are often selected after their initial financial aid offer based on scholarship-specific eligibility. These scholarships are almost always used to replace some or all of the recipient's Caltech scholarship. The Financial Aid Office makes every attempt to renew these scholarships, contingent upon the recipients continuing to meet the specific eligibility criteria.

FEDERAL GRANTS

Federal Pell Grant

Awarded to exceptionally needy undergraduate students who are seeking their first bachelor's degree. Amounts are set by the fed-

eral government based on need and enrollment status. In 2019-20, awards ranged from \$650 to \$6,195 for full-time students; awards for part-time students are set in proportion to their enrollment, i.e., three-quarter time, half-time, less than half-time. Recipients must be in good academic standing.

Federal Supplemental Educational Opportunity Grant

Awarded to undergraduates with demonstrated need who are seeking their first bachelor's degree. Priority goes to full-time Pell Grant recipients. Recipients must be in good academic standing. Awards cannot exceed \$4,000 per year.

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 \$9,084, 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.

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 \$1,672 for books and living expenses. When renewed or applied beyond the first year, awards also include tuition and fee assistance of up to \$9,084. 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.

Other State Grants

Other states, such as Pennsylvania, Vermont, and Rhode Island, may offer grant assistance to their residents who plan to attend Caltech. Students are encouraged to contact their respective state post-secondary agencies for specific eligibility and renewal criteria

EDUCATIONAL LOANS

An educational loan is a serious financial obligation and must be repaid. You should carefully consider the repayment obligation before you accept educational loans. Loans can be an invaluable resource for many students and their families in financing a college education. Students can postpone paying a portion of their edu-

cational costs until they complete their education or leave school. The repayment period on most loans can extend up to 10 years after graduation or leaving school.

Graduating with educational debt is a fairly common experience for students. At Caltech, however, the average educational indebtedness at graduation is significantly lower than the national average for students attending four-year private and public colleges. Over the last several years, the average for Caltech graduates has been among the lowest in the nation for four-year colleges.

The William D. Ford 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 room and board, 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;
3. The Federal Direct Graduate PLUS Loan Program; and
4. 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 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 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 of

- \$5,500 for first-year students, with no more than \$3,500 in subsidized Stafford;
- \$6,500 for second-year students, with no more than \$4,500 in subsidized Stafford; and
- \$7,500 for third- and fourth-year students, with no more than \$5,500 in subsidized Stafford.

Independent undergraduate students and dependent undergraduate students whose parents are unable to borrow Parent PLUS loans may borrow additional unsubsidized Stafford Loan amounts not to exceed an annual total of

- \$9,500 for first-year students, with no more than \$3,500 in subsidized Stafford;
- \$10,500 for second-year students, with no more than \$4,500 in subsidized Stafford; and
- \$12,500 for third- and fourth-year students, with no more than \$5,500 in subsidized Stafford.

Graduate students may borrow Stafford Loan unsubsidized amounts not to exceed an annual total of \$20,500.

The maximum outstanding total subsidized and unsubsidized Stafford Loan debt is

- \$31,000 for dependent undergraduate students, with no more than \$23,000 in subsidized Stafford;
- \$57,500 for independent undergraduate students (or for dependent undergraduate students whose parents do not qualify for PLUS loans), with no more than \$23,000 of this aggregate amount in the form of subsidized loans; and
- \$138,500 for graduate students (including loans for undergraduate study), with no more than \$65,500 of this aggregate in the form of subsidized loans.

Stafford Loan interest rates

The interest rate on subsidized and unsubsidized Stafford Loans disbursed for enrollment periods that begin after July 1, 2019 is currently scheduled to be fixed at 4.53% for undergraduate students.

Undergraduate students:

Enrollment Periods Beginning Between	Interest Rates	
	Subsidized	Unsubsidized
July 1, 2019 - June 30, 2020	4.53%	4.53%
July 1, 2018 - June 30, 2019	5.05%	5.05%
July 1, 2017 - June 30, 2018	4.45%	4.45%
July 1, 2016 - June 30, 2017	3.76%	3.76%
July 1, 2015 - June 30, 2016	4.29%	4.29%
July 1, 2014 - June 30, 2015	4.66%	4.66%
July 1, 2013 - June 30, 2014	3.86%	3.86%
July 1, 2011 - June 30, 2013	3.40%	6.80%
July 1, 2010 - June 30, 2011	4.50%	6.80%

July 1, 2009 - June 30, 2010	5.60%	6.80%
July 1, 2008 - June 30, 2009	6.00%	6.80%

Graduate students:

Enrollment Periods Beginning Between	Interest Rates
	Unsubsidized
July 1, 2019 – June 30, 2020	6.08%
July 1, 2018 – June 30, 2019	6.60%
July 1, 2017 – June 30, 2018	6.00%
July 1, 2016 - June 30, 2017	5.31%
July 1, 2015 - June 30, 2016	5.84%
July 1, 2014 - June 30, 2015	6.21%
July 1, 2013 - June 30, 2014	5.41%
July 1, 2006 - June 30, 2013	6.80%

To offset the federal government's cost of the program, the borrower must pay an up-front origination fee of the principal amount of the loan.

First Disbursement Made	Loan Fee
October 1, 2019 – September 30, 2020	1.059%
October 1, 2018 – September 30, 2019	1.062%
October 1, 2017 – September 30, 2018	1.066%
October 1, 2016 – September 30, 2017	1.069%
October 1, 2015 – September 30, 2016	1.068%
October 1, 2014 – September 30, 2015	1.073%
December 1, 2013 – September 30, 2014	1.072%
July 1, 2013 – November 30, 2013	1.051%

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. Complete information on

Stafford Loan deferments and repayment options is also available from the Financial Aid Office.

Federal Parent PLUS Loan

Parent PLUS loans are available to the parents or stepparents of dependent undergraduate students. These credit-based loans are not based on federal need or subsidized by the government, but students must file a FAFSA in order for their parents to qualify for a Parent PLUS loan.

Enrollment Periods Beginning Between	Interest Rates
	Unsubsidized
July 1, 2019 – June 30, 2020	7.08%
July 1, 2018 - June 30, 2019	7.60%
July 1, 2017 - June 30, 2018	7.00%
July 1, 2016 - June 30, 2017	6.31%
July 1, 2015 - June 30, 2016	6.84%
July 1, 2014 - June 30, 2015	7.21%
July 1, 2013 - June 30, 2014	6.41%
July 1, 2006 - June 30, 2013	7.90%

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. For all loans originated before July 1, 2013 there is a 4.0% origination fee assessment per loan.

First Disbursement Made	Loan Fee
October 1, 2019 – September 30, 2020	4.236%
October 1, 2018 – September 30, 2019	4.248%
October 1, 2017 – September 30, 2018	4.264%
October 1, 2016 – September 30, 2017	4.276%
October 1, 2015 – September 30, 2016	4.272%
October 1, 2014 – September 30, 2015	4.292%
December 1, 2013 – September 30, 2014	4.288%
July 1, 2013 – November 30, 2013	4.204%

For Parent PLUS loans that are first disbursed on or after July 1, 2008, parent borrowers have the option of deferring repayment based on the enrollment status of the dependent student on whose behalf a Direct PLUS loan was obtained. Specifically, Parent PLUS loan borrowers may defer repayment

- while the dependent student on whose behalf the loan was obtained is enrolled on at least a half-time basis, and
- during the six-month period after the dependent student on whose behalf the loan was obtained ceases to be enrolled on at least a half-time basis.

If a Parent PLUS loan borrower does not request a deferment, the first payment on the loan will be due within 60 days after the loan is fully disbursed.

Applications for Federal Direct Parent PLUS loans are available on the Caltech Financial Aid Office website. Applications must be submitted to the Financial Aid Office for eligibility certification. Complete information on Parent PLUS loan deferments and repayment options is also available from the Financial Aid Office.

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, he or she may contact the office at U.S. Department of Education, FSA Ombudsman Group, P.O. Box 1843, Monticello, KY 42633; (877) 557-2575; fax: (606) 396-4821; visit the website at studentaid.ed.gov/sa/repay-loans/disputes/prepare/contact-ombudsman.

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 carry 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.

The Caltech Y also has a no-interest, 30-day emergency-loan program. Maximum loans are \$50. Additional information and applications may be obtained from the Caltech Y.

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. Students should go to the Career Development Center website to see relevant job listings.

Please note that students may work no more than 16 hours per week (no more than 12 hours per week as undergraduate teaching assistants). First-year students may not work during fall term. Students can expect to earn at least the City of Pasadena minimum wage of \$14.25 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 are included in section 4, Teaching Assistantships. (See pages 351–352.)

Federal Work-Study

Awarded to domestic students who have demonstrated financial need through their submission of the FAFSA, this federally funded program provides part-time employment to eligible students.

Most Caltech students are awarded \$2,500 in Federal Work-Study (FWS). Some students may be awarded less. Since entering students are not permitted to work on-campus in the fall term and can only work in the winter and spring terms, student employment awards for entering students are limited to \$1,350 in their first year. Employment awards will increase to the standard student employment amount offered to continuing students after the first year. The maximum amount of FWS wages that a student may earn is determined by his or her financial need. Students have the option to move all or a portion of their loan or student employment from one program to the other at any time during the academic year. The final day to request to convert your loan into work or work into 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 following table to determine which deadline applies to you.

Last Term of Enrollment in Academic Year 2018-19	Hard Deadline
Fall Term	November 22, 2019
Winter Term	February 28, 2020
Spring Term	May 22, 2020

Please go to the work-study page on the Caltech Financial Aid Office website (www.finaid.caltech.edu/TypesofAid/workstudy) for additional information about student employment at Caltech.

Caltech Work-Study

The Caltech Work-Study Program is funded by the Institute and is designed to provide part-time employment for international students who have demonstrated financial need, and other students who do not qualify for the Federal Work-Study Program. The Caltech Work-Study Program is limited to on-campus employment or student employment positions at the Jet Propulsion Laboratory. The program's regulations parallel the Federal Work-Study Program's regulations.

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. (For more information on Study Abroad, see page 179.)

Costs include but are not limited to tuition, fees, room, board, 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 interest-free 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

A number of both local and national organizations offer outside scholarships to continuing students throughout the year, some of these regardless of need. Those relevant to undergraduate students will also be posted in the Scholarship News section of the Caltech Financial Aid Office website. Such scholarships can also often be found with the help of a search service. We recommend FastWeb (www.fastweb.com); College Board Fund Finder (bigfuture.collegeboard.com); and nerd scholar (www.nerdwallet.com/nerdscholar/scholarships/). (For more information on scholarship services, go to www.finaid.org). You may also visit the Financial Aid website at www.finaid.caltech.edu/typesofaid/os/list for a list of outside scholarships.

Outside scholarships acquired by students are considered, by federal regulation, to be a resource available during the academic year. Caltech's policy is to use outside scholarships to replace the student employment and/or loan components of the financial aid package. For entering students, we generally replace student employment first. For continuing students, loans are generally replaced first. Only if the total outside scholarships exceeds the student employment and/or loan that would have been included in your financial aid package will it be necessary to reduce Caltech scholarship. In general, a student's total financial aid, including outside assistance, cannot exceed his or her demonstrated financial need. Under no circumstances can a student's total financial aid, exceed their estimated cost of attendance.

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 your 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, telephone, or in person at the Bursar's Office. Prior to receiving funds, it may be necessary to fill out and sign a refund form. Refunds can be obtained in cash or by check. A maximum refund of \$500 cash per day can be received from the Bursar's Office cashier. Refund checks are requested by the Bursar's Office and issued by Accounts Payable. This usually takes five working days 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, and room and board 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. Students whose loan periods are for one term receive their entire disbursement at the beginning of that term.

If you work through either the Federal Work-Study or the Caltech Work-Study program, you will be paid by check through the biweek-

ly 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 (www.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)

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 after grades are posted at the end of each term. Failure to meet the standards of satisfactory academic progress may disqualify a student from additional federal, state and institutional financial aid. A student can appeal their unsatisfactory academic progress status and be placed on warning, probation or continued on probation for financial aid purposes.

Satisfactory Academic Progress Requirements

Following the first two terms, which are taken on a pass-fail basis, freshmen will be ineligible to register if they failed to pass at least 27 units in the previous term. After the first two terms of study, all undergraduate students must complete a minimum of 27 units with a grade-point average of at least 1.9 in order to remain eligible to register for classes. In addition, students must earn an average of 36 units per term over the past three trailing terms (that is, a minimum of 108 units should be earned after three terms of enrollment each academic year). A student may be excused from the 27-unit eligibility requirement if the requisite 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.

Following their first ineligibility, students are to meet with the dean or associate dean of undergraduate students. The dean may choose to reinstate them, in which case they will be on academic probation. 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 rein-

statement and place them on academic probation, or require them to withdraw from the Institute for at least two terms. Students who fail a core course or who fail to successfully complete 36 units, even though they remain in good standing, are required to meet with one of the undergraduate deans before being allowed to register for classes in the subsequent term.

Financial Aid Warning

Students who are found not to be making satisfactory academic progress at the end of an academic term will be placed on financial aid warning. A student may continue to receive financial aid for one term while on financial aid warning status. Students should use this opportunity to re-establish SAP.

Financial Aid Probation

Students who fail to make satisfactory academic progress after their term of financial aid warning will be ineligible to register and ineligible for financial aid. Students may appeal this status as outlined in the Caltech Catalog. Ineligible freshmen must petition the UASH Committee for reinstatement if they wish to continue as students and continue to receive financial aid. The dean of students or associate dean may act on a petition if it is the student's first ineligibility.

Undergraduate students, except first- and second-term freshmen, may submit a petition to the UASH Committee for reinstatement, giving any reasons that may exist for their previous unsatisfactory work and stating any new conditions that may lead to better results. Each such petition will be considered on its merits. For the first such ineligibility, the petition may be acted on by the 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. All subsequent reinstatements must be acted upon by the Committee.

Students who are reinstated as a result of their appeal/petition for reinstatement will be placed on financial aid probation and may receive financial aid for an additional academic term.

Continued on Financial Aid Probation

Students who fail to make satisfactory academic progress after a term on financial aid probation will be ineligible to register and ineligible for federal and state financial aid. These students may appeal this status as outlined above and in the Caltech Catalog.

Students who are reinstated as a result of their appeal/petition for reinstatement will be continued on financial aid probation. These students will be ineligible for federal and state aid. They will continue to be eligible for up to three additional terms of institutional aid but their scholarship eligibility will be reduced in each term the student is continued on financial aid probation.

Financial Aid Suspension

Students who fail to make satisfactory academic progress after being continued on financial aid probation for three additional terms will be ineligible for federal, state *and institutional financial aid*, even if they are subsequently reinstated by the UASH Committee, until such time as they make satisfactory academic progress.

Maximum Time Frame for Receiving Aid

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 ► $486 \times 150\% = 729$ 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.

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 freshmen 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 Dean or Associate Dean of Undergraduate Students. Underloads for graduating seniors must be approved by the Registrar. (See Caltech Catalog, page 202, for the underload policy.)

The following information summarizes the impact of less than full-time enrollment on financial aid. See page 197 for the separate conditions regarding eligibility to be enrolled less than full-time.

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 reduction in their tuition. 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 calculated per-unit tuition and then revise the student's aid (grant eligibility) to reflect the reduction in calculated need.

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 budget for financial aid purposes to reflect the calculated per-unit tuition and reduce the books and supplies allowance to 1/2 of the standard amount for that term. Federal Pell Grant recipients will have their Pell award reduced according to federal regulations. The Financial Aid Office will revise the student's budget to reflect the per-unit tuition and other reductions in education related costs and then revise the student's aid (grant eligibility) to reflect the reduction in calculated need. Students enrolled 1/2 time can also anticipate an increase in their work-study award for the term.

Less than 1/2 Time

Less than 1/2 time enrollment is defined as taking fewer than 18 units. Tuition is revised for financial aid purposes to reflect the calculated per-unit tuition and the books and supplies allowance is reduced to 1/4 of the standard allowance for that term. (As indicated in the Caltech Catalog, the minimum tuition charge is units per term.) The student's aid is revised based on the reduced education related costs. Federal Pell Grant recipients will have their Pell award reduced according to federal regulations. More importantly, the student/family becomes ineligible for scholarship/grant aid awarded by Caltech and for Federal Direct PLUS or Stafford loans for that term. The student will be only eligible for Caltech work-study and loan assistance.

Please note: If the student is enrolled less than half time, the grace period on any student loan (Federal Perkins Loan, Federal Direct Stafford Loan and Caltech and Institute loans) will begin.

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 Administrator. Contact the office Monday through Friday from 8:00am to 5:00pm, with any questions you have.

PRIZES

Advocating Change Together (ACT) Award

Given by the Caltech Y, this award allows students to learn about a global, national, or local issue by immersing themselves with activists working on a cause over the summer and then challenges them to educate others by creating and leading programs designed to raise awareness on campus the following year.

Robert P. Balles Caltech Mathematics Scholars Award

An annual prize is awarded to the mathematics major finishing his or her senior year who has demonstrated the most outstanding performance in mathematics courses completed in the student's time at Caltech. The executive officer for mathematics, in consultation with the faculty, determines the recipient. The prize is made possible by a gift from Mr. Robert P. Balles.

Mabel Beckman Prize

The Mabel Beckman Prize is given in memory of Mrs. Beckman's many years of commitment to Caltech's educational and research programs. The prize is awarded to an undergraduate woman 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. This prize is given at commencement.

Eric Temple Bell Undergraduate Mathematics Research Prize

In 1963 the department of mathematics established an undergraduate mathematics research prize honoring the memory of Professor Eric Temple Bell, and his long and illustrious career as a research mathematician, teacher, author, and scholar. His writings on the lives and achievements of the great mathematicians continue to inspire hundreds of students at Caltech and elsewhere. A prize is awarded annually to one or more juniors or seniors for outstanding original research in mathematics, the winners being selected by members of the mathematics faculty. The funds for this prize come from winnings accumulated over the years by Caltech undergraduate teams competing in the William Lowell Putnam Mathematics Contest, an annual nationwide competition.

Bhansali Prize in Computer Science

The Bhansali Prize was established in 2001 by Vineer Bhansali (B.S. '87, M.S. '87) in memory of his grandfather, Mag Raj Bhansali. The prize and honorarium are awarded 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 awarded to one or more freshmen, 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.

Marcella and Joel Bonsall Prize for Technical Writing

The Marcella and Joel Bonsall Prize for Technical Writing was established by the late Marcella Bonsall to encourage SURF students to develop excellent technical writing skills. Mentors may nominate their students' papers for consideration. A faculty committee recommends the winning papers. Up to five prizes may be awarded annually.

Richard G. Brewer Prize in Physics

The Richard G. Brewer Prize is awarded to the freshman with the most interesting solutions to the Physics 11 "hurdles," in recognition of demonstrated outstanding intellectual promise and creativity at the very beginning of their Caltech education. The award is a stipend that will support the student for the summer while they work on an independent Physics 11 project. This award is made possible by a gift from Dr. Richard G. Brewer, a Caltech alumnus who received his B.S. degree in chemistry in 1951.

Fritz B. Burns Prize in Geology

This prize is awarded 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.

Caltech Alumni Spirit Award

Commemorating extraordinary activities by Caltech undergraduate students, graduate students, and postdoctoral scholars who best exemplify the spirit, tradition, and values of Caltech, this award is given only when the Alumni Association finds that exceptional activities have occurred that merit this special recognition.

Bonnie Cashin Prize for Imaginative Thinking

This prize, established in 1997 by Bonnie Cashin, is awarded each year to the entering freshman who has written the most imaginative essays in the Application for Freshman Admission. The Freshman Admissions Committee will nominate awardees to the vice provost, who will approve the selection. The award may be shared if there is more than one deserving student in a particular year.

The Milton & Rosalind Chang Career Exploration Prize

The Milton (PhD '69) and Rosalind Chang Career Exploration Prize encourages and supports recent Caltech graduates who would like to explore careers outside of academia. Graduating students and recent alumni can apply for up to \$65,000 in financial support to pursue a bold, compelling, and innovative project to pursue while deliberately taking a break from their current academic or professional path in order to explore other interests, have a diversity of experiences, and develop new skills. Graduating students and alumni interested in fearlessly exploring a new career, volunteer opportunity, or enterprising project are encouraged to apply.

Robert F. Christy Prize for an Outstanding Freshman in Physics

This prize is awarded annually to a freshman 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

From a fund contributed by the Caltech Alumni Association, annual awards are made to two juniors in engineering options. The award recognizes service to the campus community and a grade-point average equal to or greater than that required for graduation with honor. 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.

Deans' Cup and Student Life Award

These two awards are presented to undergraduates whose concern for their fellow students has been demonstrated by persistent efforts to improve the quality of undergraduate life and by effective communication with members of the faculty and administration.

Doris Everhart Service Award

The Doris Everhart Service Award is given annually to an undergraduate student who has actively supported and willingly worked for organizations that enrich not only student life, but also the campus and/or 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 made possible by Sally V. Ridge and was established to honor Doris Everhart.

Richard P. Feynman Prize in Theoretical Physics

This prize was established through gifts in memory of Richard P. Feynman and the senior class gift of the class of 1989. It is awarded annually to a senior student on the basis of excellence in theoretical physics.

Haren Lee Fisher Memorial Award in Junior Physics

Mr. and Mrs. Colman Fisher established the Haren Lee Fisher Memorial Award in Junior Physics in memory of their son. The General Electric Foundation also contributed to the fund under the matching plan of their Corporate Alumnus Program. A prize will be awarded annually to a junior physics major, who is selected by a physics faculty committee as demonstrating the greatest promise of future contributions to physics.

Henry Ford II Scholar Awards

Henry Ford II Scholar Awards are funded under an endowment provided by the Ford Motor Company Fund, a nonprofit organization supported primarily by contributions from the Ford Motor Company. Awards will be made annually to the engineering students from each option with the best academic record at the end of the third year of undergraduate study, or to the engineering student with the best first-year record in the graduate program. The chair of the Division of Engineering and Applied Science names the recipients.

Jack E. Froehlich Memorial Award

The family and friends of the late Jack E. Froehlich, who did his undergraduate and graduate work at Caltech and was later the project manager for Explorer I for the Jet Propulsion Laboratory, established a prize fund that provides an award to a junior in the upper five percent of his or her class who shows outstanding promise for a creative professional career. The student is selected by the deans and the Undergraduate Academic Standards and Honors Committee.

Barry M. Goldwater Scholarship

This scholarship program honoring Senator Barry Goldwater was designed to foster and encourage outstanding students to pursue careers in the fields of mathematics, the natural sciences, and engineering. The Goldwater Scholarship is the premier undergraduate award of its type in these fields.

George W. and Bernice E. Green Memorial Prize

The George W. and Bernice E. Green Memorial Prize was established in 1963 with contributions given in memory of George W. Green, who for 15 years served on the staff of the Caltech business office and was vice president for business affairs from 1956 to 1962. The prize is awarded annually to 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 and carries a cash award of \$500.

Lucy Guernsey Service Award

Awarded to one or two students who have provided exceptional service to the Caltech Y and/or the community, are involved with service projects, have demonstrated leadership in community and volunteer service efforts, and who exemplify a spirit of service. Established by the Caltech Y ExComm in honor of Lucy Guernsey, the Y's executive director from 1989 to 1991.

John H. Hall Memorial Scholarship

This prize recognizes an outstanding undergraduate student in geological and planetary sciences.

Frederic W. Hinrichs, Jr., Memorial Award

The Board of Trustees of the California Institute of Technology established the Frederic W. Hinrichs, Jr., Memorial Award in memory of the man who served for more than 20 years as dean and professor at the Institute. In remembrance of his honor, courage, and kindness, the award bearing his name is made annually to the senior who throughout his or her undergraduate years at the Institute has made the greatest contribution to the student body and whose qualities of character, leadership, and responsibility have been outstanding. At the discretion of the deans, more than one award, or none, may be made in any year. This award is given at commencement.

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 freshman humanities course. The prize is administered by the writing center, and the winner will be chosen by a committee from the humanities division.

The George W. Housner Prize for Academic Excellence and Original Research

The George W. Housner prize is given annually to a senior in the upper 20 percent of his or her class who has demonstrated excellence in scholarship and in the preparation of an outstanding piece of original scientific research. The student is selected by the deans and the Undergraduate Academic Standards and Honors Committee. At the discretion of the dean, more than one award may be made in any year. The prize, presented at commencement, consists of a cash award and a certificate. This prize is made possible by a gift from George W. Housner, Carl F Braun Professor of Engineering, Emeritus.

Patrick Hummel and Harry Gray Travel Fund

Established as a joint gift from Carla and Paul Hummel, Patrick Hummel, and Shirley and Harry Gray, Caltech's Arnold O. Beckman Professor of Chemistry and founding director of the Beckman Institute, the endowed fund supports undergraduate travel opportunities that promote professional and leadership development and broaden students' perspectives as engaged, responsible citizens of the world.

Bibi Jentoft-Nilsen Memorial Award

Family and friends of Bibi Jentoft-Nilsen, class of 1989, have provided this award in her memory. This cash award is for an upper-class student who exhibits outstanding qualities of leadership and who actively contributes to the quality of student life at Caltech.

Dr. James King Jr. Student Diversity Award

The Dr. James King Jr. award recognizes individuals who stand out as strong supporters of diversity within the Caltech student body. The award is named in honor of Dr. King, who was the first African American to receive a Ph.D. from Caltech in chemical physics (at that time it was chemistry and physics, and was the assistant laboratory director at JPL. King had a reputation for mentoring students and encouraged diversity in the Caltech student body.

D. S. Kothari Prize in Physics

This prize was established in 1998 in memory of Dr. D. S. Kothari, who received his Ph.D. under Lord Rutherford in 1933, and subsequently made significant contributions in theoretical astrophysics and science education. The award is given each year to a graduating senior in physics who has produced an outstanding research project during the past year.

Margie Lauritsen Leighton Prize

From a fund established by Dr. Fay Ajzenberg-Selove and Dr. Walter Selove, the departments of physics and astrophysics will annually award the Margie Lauritsen Leighton Prize to one or two undergraduate women who are majoring in physics or astrophysics, and who have demonstrated academic excellence.

Library Friends' Senior Thesis Prize

This prize was established by the Friends of the Caltech Libraries in 2010 to recognize senior theses that exemplify research and the effective use of library information resources. The thesis is an extensive, independent written work produced during the senior year, usually within a senior thesis course series. The University Librarian and the Friends of the Caltech Libraries oversee evaluation and make recommendations to the Undergraduate Academic Standards and Honors Committee for final selection. An oral presentation may be requested. At the discretion of the Friends of the Caltech Libraries, more than one award, or none, may be made in any year.

Mari Peterson Ligocki (B.S. '81) Memorial Fund

This award is made to one student who, through his or her personal character, has improved the quality of student life at Caltech. It recognizes the student who provides quiet support and kind encouragement to peers. This fund was established by Mr. José F. Helú Jr. (B.S. '79) to honor the memory of Mari Peterson Ligocki, who possessed these qualities. The award consists of dinner for two at the recipient's choice of a fine restaurant, and a grant toward any project or cause of the recipient's choosing. It may be seed money for a project in any field, whether science-related or not.

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

Awarded to a candidate for the degree of Bachelor of Science 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. The prize consists of a citation and a cash award.

James Michelin Scholarstauhip

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 award recognizes undergraduate students for their contributions to the field of geology or geophysics.

Robert L. Noland Leadership Award

The Robert L. Noland Leadership Award is for upperclass students who exhibit special qualities of leadership. Students who have motivated others to live up to their leadership potential or who have provided excellent "behind the scenes" work in campus activities are those for whom this award is intended. The kind of leadership to be recognized is most often expressed in personal actions that have helped other people and that have inspired others to fulfill their leadership capabilities. The scholarship was set up by Ametek in 1978 in honor of its president, Robert L. Noland, a Caltech alumnus. Two or more awards are generally made each year.

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.

Doris S. Perpall SURF Speaking Prize

Robert C. Perpall (B.S. '52, M.S. '56) endowed this prize in memory of his late wife, Doris S. Perpall, to encourage students to prepare excellent SURF presentations. SURF Seminar Day is the first round of the Perpall Speaking Competition. The best presentations in each session are nominated for advancement to a second round, held in November. The final round is held in January. Three prizes are awarded annually.

Howard Reynolds Memorial Prize in Geology

The Howard Reynolds Memorial Prize in Geology 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 student life at Caltech.

Herbert J. Ryser Scholarships

The Herbert J. Ryser Scholarships were established in 1986 in memory of H. J. Ryser, who was professor of mathematics at Caltech from 1967 to 1985. Professor Ryser contributed greatly to combinatorial mathematics and inspired many students with his carefully planned courses. The scholarships are given on the basis of merit, preferably in pure mathematics. Recipients are selected by the executive officer for mathematics after consulting the faculty.

San Pietro Travel Prize

This prize is awarded to one or more sophomores, juniors, or seniors to fund an adventurous and challenging summer experience that expands the recipient's cultural horizons and knowledge of the world.

Richard P. Schuster Memorial Prize

This Award is made from funds established by family, friends and colleagues of Richard P. Schuster, Jr., a graduate of Caltech and the Institute's Director of Development at the time of his death. The recipient is a junior or senior in Chemistry or Chemical Engineering; selection is based on financial need and a demonstration of 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 will be awarded annually to an undergraduate or graduate student whose work in history or the social sciences exemplifies Eleanor Searle's interests in the use of power, government, and law.

Dr. Fred Shair Award for Program Diversity

The Dr. Fred Shair Award is given to individuals who stand out as strong supporters of programs that increase the diversity and pluralism in practice at Caltech. Dr. Shair was a member of the chemical engineering faculty, and one of his great accomplishments and contributions to the campus was the creation of the Summer Undergraduate Research Fellowships (SURF) program in 1979. He later included high-achieving students from campuses across the country in an effort to support equity in access to Caltech's research communities.

Renuka D. Sharma Prize and Award in Chemistry

This prize was established in 2009 by Professor Brahma D. Sharma, in memory of his daughter Renuka D. Sharma, to be given to a sophomore who has demonstrated outstanding performance in chemistry during his or her freshman year. The prize was donated to encourage scholastic achievement early in a student's career and is administered by the Division of Chemistry and Chemical Engineering.

C.S. Shastry Prize in Physics

The C.S. Shastry Prize in Physics will support a research fellowship for one sophomore undergraduate student conducting research in physics during the summer quarter under the guidance of a Caltech faculty member. The recipient will be nominated by a faculty member based on criteria valued by Professor Shastry: passion for the subject, curiosity about nature, and demonstrated ability. Preferably, the Awardee shall be a student majoring in physics who has completed Caltech's Physics 11 course, and who intends to pursue a research career in physics. The prize is made possible by a gift from Dr. Murali Sharma, a Caltech alumnus who received his Ph.D. in Physics in 1993.

Don Shepard Award

Relatives and friends of Don Shepard, class of 1950, have provided this award in his memory. The award is presented to a student, the basic costs of whose education have already been met but who would find it difficult, without additional help, to engage in extra-curricular activities and in the cultural opportunities afforded by the community. The recipients—freshmen, sophomores, and juniors—are selected on the basis of their capacity to take advantage of and to profit from these opportunities, rather than on the basis of their scholastic standing.

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 literature faculty to the student who writes the finest essay on Shakespeare.

Paul Studenski Memorial Fund Prize

This travel grant is awarded to a Caltech undergraduate who would benefit from a period away from the academic community in order to obtain a better understanding of self and his or her plans for the future. The recipient is selected by the Caltech Y Studenski Committee.

Olga Taussky-Todd Prize

The Olga Taussky-Todd Prize was established by an alumna of Caltech to support women in Mathematics at Caltech. Professor Taussky-Todd (1906-1995) was a pioneer in computer science and algebraic number theory. She was also the first woman to receive a full professorship at Caltech and advised the Institute's first female Ph.D. in Mathematics, Lorraine Foster. The prize will support outstanding undergraduate students majoring in Mathematics through research fellowships and other support to broaden their academic experience.

Morgan Ward Prize

The Morgan Ward Prize was established by the department of mathematics in 1963 to honor the memory of Professor Morgan Ward in recognition of his long service to mathematics and to the Institute. The competition is open only to freshmen and sophomores. An entry consists of a mathematical problem together with a solution or a significant contribution toward a solution. One or more winners are selected by a faculty committee acting on the advice of student judges. Each prize is funded by the same source used to sponsor the Eric Temple Bell Prize.

Women Mentoring Women: Candace Rypisi Outstanding Mentor Award

This prize recognizes a woman who has demonstrated a willingness to share their knowledge to enhance the professional and personal development of her mentee(s), provided emotional and moral support and encouragement, enhanced or helped facilitate access to career-related information and exposure to various professional resources, opportunities, networks, and other role models, and promoted the mentee's sense of competence and confidence.

Women Mentoring Women: Helen McBride Outstanding Mentee Award

This award recognizes a woman who has demonstrated a sincere desire to succeed as a student, who is committed to her personal development, open and willing to learn from her mentor, and who is receptive to advice and counsel. The recipient will have worked

with her mentor to establish realistic goals, and demonstrated a commitment to carrying them out.

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. The award is given to a pure or applied mathematics student in his or her sophomore or junior year selected by the faculty in pure and applied mathematics. The award recognizes 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 residence regardless of unit load each term or the total units earned. The four-year residence 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 freshmen for 2019-20. 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. Freshman Mathematics (Ma 1 abc)	27
2. Freshman Physics (Ph 1 abc)	27
3. Freshman Chemistry (Ch 1 ab)	15
4. Freshman Biology (Bi 1 or Bi 1 x) ¹	9
5. Menu Class (currently Ay 1, EE 1, ESE 1, Ge 1, or IST 4)	9
6. Freshman Chemistry Laboratory (Ch 3 a) ²	6
7. Additional Introductory Laboratory	6
8. Scientific Writing ³	3
9. Humanities Courses (as defined below)	36
10. Social Sciences Courses (as defined below)	36
11. Additional Humanities and Social Sciences Courses	36
12. Physical Education	9

¹ The biology core requirement can be met by either Bi 1 or Bi 1x. Alternatively, the requirement may be fulfilled by taking both Bi 8 and Bi 9. Nine units must be taken on grades.

² This requirement can also be met by completing Ch 3 x, Ch 4 a, Ch 8, or Ch/ChE 9.

³ This requirement may be met either by taking a course approved by the student's option to satisfy this requirement, or by taking En/Wr 84.

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.

Introductory Laboratory Requirement

All students are required to take at least 12 units of laboratory work in experimental science during their freshman and sophomore years. Ch 3 a (6 units) or Ch 3 x (6 units) shall be taken during the freshman year. The additional 6 units must be chosen from one of the following: APH/EE 9 ab (6 units), APH/EE 24 (9 units), Bi 1x (9 units but only if Bi 1x 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), Ph 3 (6 units), Ph 5 (9 units), Ph 8 bc (6 units), or a more advanced laboratory. Computational laboratory courses may not be used to satisfy this requirement.

Humanities and Social Sciences Requirements

All students must complete satisfactorily 108 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 36 in the social sciences (anthropology, business economics and management, economics, law, political science, psychology, and social science), in each case divided equally between introductory and advanced courses. 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 freshman humanities may be counted toward the 108-unit requirement.

Entering freshmen are required to take two terms of freshman humanities; that is, cross-listed humanities courses numbered 50 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 freshman humanities is a prerequisite for all humanities courses, except for foreign languages. It is *not* a prerequisite, however, for introductory social sciences. The freshman humanities classes may be taken in any two terms of the freshman year.

To encourage breadth, students will have to take their two freshman 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 freshman 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 freshman humanities, all freshmen 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 1, 2, 3, 4 and/or 50 before entering either freshman 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 An 14 or An 15, Ec 11, PS 12, or Psy 13. The 18 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
An 14 or 15	advanced anthropology
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 An 14 and Ec 11 may use 18 units of advanced anthropology courses, or 18 units of advanced economics, or 9 units of advanced anthropology and 9 units of advanced economics to fulfill the advanced social science requirement.

Included in the 12 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, Ec 105, Ec 129, Ec 130, Ec 140, PS 99 ab, 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 scientific writing requirement can be satisfied by taking an appropriate course offered by any division, or by taking En/Wr 84. 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	
	<i>Oral</i>	<i>Written</i>
ACM, APh, CNS, CS, EE, EAS, ME	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 84	same
ChE	ChE 126	Ch/ChE 91
Ch	Ch 90	Ch/ChE 91
En, H, HPS, PI	En/Wr 84	same
GPS	See Option Requirements	En/Wr 84 or one of SEC 11, SEC 12, or SEC 13
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.

		<i>Units per term</i>		
		<i>1st</i>	<i>2nd</i>	<i>3rd</i>
Ma 1 abc	Freshman Mathematics	9	9	9
Ph 1 abc	Freshman Physics	9	9	9
Ch 1 ab	General Chemistry	6	9	-
Bi 1	Principles of Biology	-	-	9
Ch 3 a	Fundamental Techniques of Experimental Chemistry ¹	6	or 6	or 6
	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.	9	9	9
	Introductory laboratory courses ²	x	x	x
	Menu course ³ or additional electives	x	x	x
PE	Physical education ⁴	3	3	3

x—Except for the minimum laboratory unit requirement, the number of units chosen here is optional. 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. First- and second-term freshmen will be limited to 45 units of classroom and laboratory courses. 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.

¹ *This course is offered in each of the three terms. Students may also take Ch 3 x.*

² *The additional 6 units must be chosen from one of the following: APh/EE 9 ab (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), Ph 3 (6 units), Ph 5 (9 units), Ph 8 bc (6 units) or a more advanced laboratory course.*

³ *Students must take a menu course in their freshman 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.

⁴ *Three terms (9 units) of PE are required for the B.S. degree. Students need not elect to take the required PE in the freshman 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, freshmen are encouraged to participate in freshman seminar classes, frontier classes, research tutorials and other research opportunities.

Starting in the 2011–12 academic year, Caltech began offering a series of freshman seminars in which 10 to 15 freshmen and a faculty member explore in depth an exciting topic in the lab, around a table, or in the field. These courses, described on page 6, cover a wide range of topics, including earthquakes, gravitational waves, and the science of music. Instructors may allow upperclassmen to enroll in these seminars after the conclusion of the pre-registration period for the upcoming term.

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 freshmen 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 freshmen: one in physics, one in biology, and one in chemistry. These tutorials have many of the same features as the freshman seminars. In physics, the research tutorial includes approximately seven freshmen 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 on page 10.

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 (ACM)

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. Courses may be used to simultaneously fulfill requirements in both options. To enroll in the program, the student should meet and discuss his/her 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. The analytical tracks of Ma 1 bc are required.
2. Programming Fundamentals: CS 1; ACM 11.
3. Communication Fundamentals: SEC 10; SEC 11, SEC 12, or SEC 13.
4. Core Classes:
 - a. Introductory Methods: ACM 95 ab.
 - b. Linear Algebra: ACM 104 or ACM 107.
 - c. Probability: ACM 116 or CMS 117.
 - d. Mathematical Methods: ACM 101 ab.
 - e. Numerical Analysis: ACM 106 ab.
5. ACM Electives: In addition to all of the above requirements, three 100+ ACM courses approved by the advisor; up to 9 units of ACM 80 abc or ACM 81 abc can be counted towards this requirement with advisor 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 Bi 8, Bi 9, Ch 21 abc, Ch 25, Ch 41 abc, Ph 2 abc, or Ph 12 abc.

ACM Typical Course Schedule

		<i>Units per term</i>		
		<i>1st</i>	<i>2nd</i>	<i>3rd</i>

Second year

Ma 2	Differential Equations	9	–	–
Ma 3	Intro. to Probability and Statistics	–	9	–

Ma 6 abc Altern. Ma 121 ab + CS 21 (9/18/0)	Intro. to Discrete Mathematics	9	9	9
Science Requirement	See requirements listed above	9	9	-
ACM 11	Intro to Matlab and Mathematica	-	-	6
CS 1	Intro. to Computer Programming	9	-	-
	HSS electives	9	9	9
	Electives (see option require- ments 5, 6 above)	-	9	21
	Total	45	45	45

Third Year

Ma 108 abc	Classical Analysis	9	9	-
ACM 95 ab	Intro. Methods of Applied Math	-	12	12
ACM/IDS 104 (or 107)	Appl. Linear Algebra	9	-	-
ACM/EE/ IDS 116 (or 117)	Intro. To Probability Models	9	-	-
	HSS electives	9	9	9
	Electives (see option requirements 5, 6 above)	9	12	12
E 10	Technical Seminar Presentation	-	3	-
E 11	Written Tech. Comm. in Engrng and Appl. Sci.	-	-	3
	Total	45	45	36

Fourth Year

ACM/IDS 101 ab	Methods of Appl. Math	12	12	-
ACM 106 ab	Intro. Methods of Comput. Math	12	12	-
ACM/IDS 216	Markov Chains, Discrete Stochastic Processes and Appl. Mathematical Optimization	-	9	-

CMS/ACM/ IDS 113	Mathematical Optimization	9	-	-
	HSS elective	9	9	9
	Electives	-	-	27
	Total	42	42	36

APPLIED PHYSICS OPTION (APh)

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 multiwavelength fiber telecommunications, integrated microphotonic and nanophotonic devices, holographic data processing and storage, and optical approaches to quantum computation; Solid-state materials and device work including nanostructured materials and devices, 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

Note: Items in brackets represent optional replacements.

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. Any three of the following: APh/EE 9 b, APh/EE 23, APh/EE 24, Ph 3, Ph 5, Ph 6, or Ph 7.
3. Ph 12 abc, APh/MS 105 ab [Ae/ME 118 or ChE/Ch 165 or Ph 127a; ChE/Ch 164 or Ph 127b], Ph 106 abc, and Ph 125 ab [Ch 125 ab]
4. Ma 2, Ma 3, and ACM 95 ab.
5. Either APh 78 abc or APh 79 abc, or one term of APh 77 and

one term of any of the following: Ph 77, EE 91, Ch 6, Ae/APh 104 bc, or MS 90. Any substitutions or additions require prior approval of the option representative.

6. One additional advanced sequence of APh courses numbered over 100, such as: APh 101 abc, APh/MS 105 abc, APh 114 abc, APh/Ph 115 and APh/Ph/Ae 116, APh/EE 130, 131, and 132, APh 156 abc, APh 190 abc, or BE/APh 161 and 162. 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

		<i>Units per term</i>		
		<i>1st</i>	<i>2nd</i>	<i>3rd</i>
<i>Second Year</i>				
ACM 95ab	Intro. Methods of Applied Math.	-	12	12
Ma 2	Differential Equations	9	-	-
Ma 3	Intro. to Probability and Statistics	-	9	-
Ph 12abc	Waves, Quantum Mechanics and Statistical Physics	9	9	9
	HSS Electives	9	9	9
	Laboratory Electives ¹	6	6	6
	Other Electives ²	9	-	9
	Total	42	45	45
<i>Third Year</i>				
APh 105ab	States of Matter	9	9	-
APh 110ab	Topics in Applied Physics	2	2	-
Ph 106abc	Topics in Classical Physics	9	9	9
Ph 125ab	Quantum Mechanics	9	9	-
	HSS Electives	9	9	9
	Other Electives ²	9	9	27
	Total	47	47	45

Fourth Year

APh 78abc or APh 79abc	Senior Thesis ¹ or Senior Thesis, Theoretical ³	9	9	9
Or APh 77	Laboratory in Applied Physics ³	-	9	9
	Advanced Electives ²	9	9	9
	HSS Electives	9	9	9
	Other Electives including APh 100	18	18	18
	Total	45	45	45

¹ See item 2, option requirements.

² See item 6, option requirements.

³ See item 5, option requirements.

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 (Ay)

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 his or her interest in research, and to provide a basis for graduate work in astronomy/astrophysics.

Undergraduate Information

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 his or her 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, and Ph 106 abc.
2. Any three of Ph 3, Ph 5, Ph 6, Ph 7, or Ay 105. APh 23 and 24

- taken as a pair may be substituted for one of these labs.
- 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.
 - 27 additional units of science or engineering electives, of which 18 must be outside the Division of Physics, Mathematics and Astronomy. ACM 95 ab is a popular choice. Core classes (see pages 233–238) or other introductory-level courses such as CS 1 do not count toward fulfillment of this requirement.
 - 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 Typical Course Schedule

		<i>Units per term</i>		
		<i>1st</i>	<i>2nd</i>	<i>3rd</i>
<i>Second Year</i>				
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 1051	Astronomy Instrumentation Lab	-	-	9
	Ay/Ph Electives	9	9	9
Ay 78	Senior Thesis	9	9	9
Ph 1213 or Ay 117	Computational Analysis	-	6	-
Ay 141 b3	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 ACM 95 is a popular choice for Option Requirement 4. Other courses may also be used.

³ Strongly recommended courses for Option Requirement 3. Other courses may be substituted.

⁴ Phys 125c is strongly 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. 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 3 terms of Ay 142. Computational skills may be acquired through Ph 20–21, 121, Ay 117, ACM 106, or equivalent classes. 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 he or she 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, APh 17, APh/EE 23/24, Ay 104, Ay 105, Ay 117, Ay 121–127, Ch 125, EE 45, EE/Ae 157, Ge/Ay 11 c, Ge 103, Ge/Ch 128, Ge 131, Ge/Ay 132, 133, 137, 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).

BIOENGINEERING OPTION (BE)

BE Aims and Scope

The undergraduate bioengineering option provides a foundation for graduate studies and career paths that requires 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 1; BE/APh 161; ChE/BE 163; two courses from BE 150, BE 159, and BE/CS/CNS/Bi 191 a.
2. Experimental methods: Bi 1x; one of BE/EE/MedE 189 a or BE 107; one of ChE 130 or BE/CS 196 a. Students are strongly encouraged to enroll in Bi 1x as freshmen; Bi 1x must be completed by the sophomore year. Nine units of BE 98 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 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; Ch 25; Ch 41 a; Bi/Ch 110. One advanced biology course of at least 9 units selected from Bi/Ch 111, Bi 114, Bi 117, Bi 122, Bi 145 ab, Bi/CNS/NB/Psy 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 (up to 12 units), any BE course numbered 100 or above, any of the BE-approved electives listed below, or any relevant class approved by the student's adviser. Additionally, courses listed in requirements 1-4 that are not used to fulfil 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 105, Bi/CNS/NB 162, Bi 190.

Biodevices: EE 112, EE 113, EE/MedE 114 ab, APh/EE 9 ab, EE 45, EE 111, EE 151.

Biomechanics: ME 19 ab, ME 12 abc, ME 14, Ae/APh/CE/ME 101

abc, Ae/APh/CE/ME 102 abc, Ae/APh 104 abc.
Synthetic biology: Ch 41 bc, ChE/Ch 148, ChE/Ch 164, ChE/Ch 165.

BE Typical Course Schedule

(Specific courses are representative and may be substituted per option requirements.)

		<i>Units per term</i>		
		<i>1st</i>	<i>2nd</i>	<i>3rd</i>
<i>First Year</i>				
Ma 1 abc	Freshman Mathematics	9	9	9
Ph 1 abc	Freshman Physics	9	9	9
Ch 1 ab	General Chemistry	6	9	-
Ch 3 a	Fundamental Techniques of Experimental Chemistry	-	6	-
CS 1	Introduction to Computer Programmng	9	-	-
	Freshman Humanities	9	-	9
Bi 1 x	The Great Ideas of Biology: Exploration through Experimentation	-	-	9
BE 1	Frontiers in Bioengineering	-	1	-
Bi 8	Introduction to Molecular Biology	-	9	-
Bi 9	Cell Biology	-	-	9
Total		42	43	45
<i>Second Year</i>				
Ma 2, Ma 3	Sophomore Mathematics	9	9	-
Ph 2 ac	Sophomore Physics	9	-	9
Ch 41 a	Organic Chemistry	9	-	-
Ch 25	Introduction to Biophysical Chemistry	-	-	9
ChE/BE 163	Introduction to Biomolecular Engineering	12	-	-
BE/CS 196 a	Design & Construction of Programmable Molecular Systems	-	12	-

BE/EE/MedE 189a	Design and Construction of Biodevices	-	-	9
	Menu course	-	-	9
	HSS electives	-	18	9
	Physical education	3	3	-
	Total	42	42	48

Third Year

ACM/EE/IDS 116	Introduction to Probability Models	9	-	-
ACM 95 ab	Introductory Methods of Applied Mathematics	-	12	12
	Advanced BE Electives	9	9	18
Bi/Ch 110	Introduction to Biochem- istry	12	-	-
	Undergraduate Research in Bioengineering	-	6	6
	HSS	9	18	9
	Total	39	45	45

Fourth Year

Bi/BE 24	Scientific Communication for Biological Scientists and Engineers	6	-	-
BE/Aph 161	Physical Biology of the Cell	-	12	-
BE/CS/CSN/Bi 191 a	Biomolecular Computation	-	9	-
BE 150	Biological Circuit Design	-	-	9
	Advanced Biology Elective	-	-	9
	Misc. Elective	9	-	9
BE 98	Undergraduate Research	9	9	9
	HSS	9	9	9
	Physical Education	3	-	-
	Total	36	39	45

BIOLOGY OPTION (Bi)

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 the Career Development Center or Professor David Chan 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 in freshman year and Bi 22. Freshmen taking Bi 8 must maintain shadow grades that indicate satisfactory progress.

1. Bi 8, Bi 9, Bi 117, Bi 122, Bi/CNS/NB/Psy 150, and Ch 41 abc.

2. Ma 2, Ma 3, and any two terms of Ph 2 abc. These courses need not be taken consecutively or in a fixed order. 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; and (2) Essentially similar scope of subject matter as the course replaced, e.g. Ch 25 for Ph2c. 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 Bi/Ch 110, 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 total of 170 units of biology must be taken and passed (Bi 1, Bi 2, and Bi 10 cannot be counted toward this total). Units within this total which are not accounted for by the requirements above are biology electives. Biology electives must include at least 8 biology classes which satisfy the following:
 - a. At least four elective courses taken for letter grades.
 - b. At least two elective courses, of at least nine units each, taken on letter grades.
 - c. Substantial lab research for credit (Bi 22) beyond the 12-unit minimum can be counted among the electives.
7. 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 Bi8 and Bi9 in their first year, to open access to the widest range of biology electives.
- Students may place out of the option requirement to take Bi 8 by passing an exam and then earning a passing grade in Bi/Ch 111 instead. The exam for placing out of Bi 8 is given late in the fall term of freshman year if specifically requested by students who have an unusually strong background in biology, e.g., substantial research experience. Some students who score a 5 on the advanced placement exam in biology may also qualify to take the exam. The placement exam is given by direct arrangement between the interested students and the faculty teaching Bi8.
- Bi 10 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.
- Ch 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/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)

		<i>Units per term</i>		
		<i>1st</i>	<i>2nd</i>	<i>3rd</i>
<i>First Year</i>				
Ma 1 abc	Freshman Mathematics	9	9	9
Ph 1abc	Freshman Physics	9	9	9
Ch 1ab	General Chemistry	6	9	-
Ch 3a	Chemistry Lab	-	6	-
6	Freshman Humanities	9	-	9
CS 1	Introduction to Computer Programming	9	-	-
Bi 8	Introduction to Molecular Biology	-	9	-
Bi 9	Cell Biology	-	-	9
Bi 10	Introductory Biology Laboratory	-	-	6
Total		42	42	42
<i>Second Year</i>				
Ma 2	Differential Equations	9	-	-
Ma 3	Introduction to Probability and Statistics	-	9	-
Ph 2 ab	Sophomore Physics	9	9	-
Ch 41abc	Organic Chemistry	9	9	9

	Introductory Social Sciences	9	9	-
	Advanced Humanities	-	-	9
Bi 122	Genetics	9	-	-
Bi 117	Developmental Biology	-	9	-
Bi/CNS/NB/ Psy 150	Introduction to Neuroscience	-	-	10
Bi 160	Molecular Evolution	-	-	9
Bi 22	Undergraduate Research	-	-	10+
	Total	45	45	47+

Third Year

	Advanced Humanities	-	-	9
	Advanced Social Sciences	9	-	9
	Additional HSS	-	-	9
Bi 145 ab	Tissue and OrganPhysiology	9	9	-
Bi/Ch 110	Introduction to Biochemistry	12	-	-
Bi/BE 24	Technical Communication (Fall or Spring)	6	-	6
Bi 118	Morphogenesis Developmental Systems OR	-	9	-
Bi/BE 182	Gene Network Design	-	9	-
Bi/Ch 111	Biochemistry of Gene Expression	-	12	-
BE/Aph 161	Physical Biology of the Cell	-	12	-
Bi/CNS/NB 154	Principles of Neuroscience	9	-	-
	OR			
Bi/CNS/NB 164	Tools of Neurobiology	9	-	-
Bi/CNS 158	Vertebrate Evolution	-	-	9
Bi 188 or 190	Human OR Systems Genetics	-	-	6
	Total	45	42	48

Fourth Year

	Additional HSS	9	9	9
Bi 114	Immunology	-	9	-
Bi/BE 129	Biology and Treatment of Cancer	-	9	-
Bi 90	Undergraduate Thesis	12+	12+	12+
Bi 192	Introduction to Systems Biology	6	-	-
BE/Bi 103 a	Introduction to Data Analysis in the Biological Sciences	9	-	-
Bi/CNS/NB 195	Mathematics in Biology	9	-	-
Bi/NB/BE 155	Neuropharmacology	-	6	-
Bi 189	The Cell Cycle	-	-	6
Bi/CNS/NB 152	Neural Circuits	-	-	6
Bi 214	Stem Cells	-	-	9
	Total	45+	45+	42+

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. *Organic Chemistry fundamentals*. Ch 41a.
3. *Intermediate Biology*. Bi 122; Bi 117; and Bi/CNS/NB/Psy 150.
4. *Advanced Biology*. 18 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 advisor or the option representative.

BUSINESS, ECONOMICS, AND MANAGEMENT OPTION (BEM)

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, and developing new ventures;
- an ability to analyze business problems using qualitative and quantitative methods;
- an ability to analyze financial and business data;
- 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, and PS/Ec 172.
2. BEM 102 and BEM 103.
3. Three courses out of BEM 104, BEM 105, BEM 110, or BEM 117.
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 (may be taken pass/fail): any BEM courses (excluding the ones listed under 1 and 2 above), ACM 113, ACM/EE 116, An/PS 127, BEM/Ec 150, CS/SS/Ec 149, Ec/ACM/CS 112, Ec 105, 121 ab, 129, 130, 131, 135, Ec/PS 160 abc, Ge/ESE 118, Ma 112a, Ma/ACM 144ab, PS 12, and Psy 13. 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.
6. 45 additional units of science (including anthropology, 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 10 (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

		<i>Units per term</i>		
		<i>1st</i>	<i>2nd</i>	<i>3rd</i>
<i>Second Year</i>				
Ma 2 & Ma 3	Sophomore Mathematics	9	9	-
Menu Course		-	-	9
Ec 11	Introduction to Economics	9	-	-
BEM 102	Introduction to Accounting	-	-	9
BEM 103	Introduction to Finance	9	-	-
PS/Ec 172	Game Theory	-	9	-
	Electives ¹	18	27	27
		45	45	45
<i>Third Year</i>				
BEM 104	Investments	-	9	-
BEM 105	Options	9	-	-
Ec 122	Econometrics	9	-	-
	Electives ¹	27	37	45
	Total	48	45	45
<i>Fourth Year</i>				
En/Wr 84	(or 3 unit course in oral communications and a scientific writing requirement course)	-	-	9
Ec 105	Firms, Competition, and Industrial Organization	9	-	-
BEM110	Venture Capital	-	9	-

Electives	36	36	36
Total	45	45	45

¹ See option requirements 4 and 5

CHEMICAL ENGINEERING OPTION (ChE)

The chemical engineering option is designed to prepare its students for either graduate study or research and development work in industry. This is accomplished by providing broad and rigorous training in the fundamentals of chemical engineering while maintaining a balance between classroom lectures and laboratory experience. The program also strives to develop in each student self-reliance, creativity, professional ethics, an appreciation of the societal impact of chemical engineering, and an understanding of the importance of continuing intellectual growth.

Chemical engineering involves applications of chemistry, physics, mathematics, and, increasingly, biology and biochemistry. In addition to these disciplines, the chemical engineering curriculum includes the study of applied and computational mathematics, fluid mechanics, heat and mass transfer, thermodynamics, chemical kinetics and chemical reactor design, and process control. Because of this broad-based foundation that emphasizes basic and engineering sciences, chemical engineering is perhaps the broadest of the engineering disciplines.

Because many industries utilize some chemical or physical transformation of matter, the chemical engineer is much in demand. He or she may work in the manufacture of inorganic products (ceramics, semiconductors, and other electronic materials); in the manufacture of organic products (polymer fibers, films, coatings, pharmaceuticals, hydrocarbon fuels, and petrochemicals); in other process industries; or in the biotechnology, pharmaceutical, or biomedical industries. Chemical engineering underlies most of the energy field, including the efficient production and utilization of coal, petroleum, natural gas, and newer technologies such as biofuels, fuel cells, and solar energy conversion technologies. Air and water pollution control and abatement and the study of climate change, its impacts, and its mitigation are also within the domain of expertise of chemical engineers. The chemical engineer may also enter the field of biochemical engineering, where applications range from the utilization of microorganisms and cultured cells, to enzyme engineering and other areas of emerging biotechnology, to the manufacture of foods, to the design of artificial human organs. In addition, the chemical engineer may use computational methods – from the atomic, molecular, and continuum levels to the chemical process, plant, and enterprise levels – to improve understanding; design experiments & interpret data; predict key attributes; and develop new or improve existing materials, methods, and processes.

Key educational objectives of our chemical engineering curriculum are to prepare students for professional practice at the forefront of

chemical engineering or for graduate school, and to become leaders in engineering, science, academia, business, and public service in a continually changing world. To do this, the curriculum focuses on developing an ability to synthesize and apply knowledge from the many subjects studied to the design of systems, components, processes, or experiments, subject to technical, economic, environmental, and/or social constraints. Problems illustrating the design process are integrated into the core courses.

Freshmen normally take the core courses in mathematics, physics, chemistry, and biology (Ma 1 abc, Ph 1 abc, Ch1 ab, and Bi 1), as well as general chemistry laboratory (Ch3a [or Ch 3x]).

Sophomores take ordinary differential equations (Ma 2), wave physics (Ph 2a), and organic chemistry laboratory (Ch/ChE 9). They also take the second-year organic chemistry course Ch 41 abc, and the basic chemical engineering courses (ChE 15, ChE 62, and ChE 63 ab). The third-year applied and computational mathematics course (ACM 95 ab) may be taken in the junior or sophomore years.

Undergraduate research is emphasized, and students are encouraged, even in the freshman year, to participate in research with the faculty. In order to obtain a basic intellectual background, all students take courses in the fundamentals of chemical engineering through the junior year. During the junior and senior years, students diversify into one of five tracks (biomolecular, environmental, materials, process systems or computational), where they pursue concentrated study in their chosen area of chemical engineering. An optional senior thesis provides an opportunity to pursue independent research and design in lieu of one of the senior laboratories.

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 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 abc, Ch 41 abc, ChE 62, ChE 63 ab, Ch/ChE 91 (or En/Wr 84), ACM 95 ab, ChE 101, ChE 103 abc, ChE 105, ChE 126, and one of Ec 111, BEM 102, or BEM 1031.
2. Completion of a track (biomolecular, environmental, process systems, materials or computational), each consisting of at least 72 units of science or engineering courses. Students should inform the executive officer 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: ChE/BE 163, Bi/Ch 110, [ChE 130 or ChE 90 c], and additional units of bioengineering or biochemical engineering electives or approved related courses.^{3,4}

b. Environmental track: two of the core ESE courses [ESE 101, 102, and 103], [ChE 128 or ChE 90 c], and additional units of ESE electives or approved related courses.^{3,4}

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.

d. Materials track: [ChE 128 or ChE 90 c]; one course on materials synthesis or processing selected from [Ch/ChE 1472, ChE 1152, or MS 133]; at least one course on the physical basis of structure and properties selected from [Ch 120, ChE/Ch 1482, MS 115, MS/APh 122, MS 131, or MS 132]; and additional units of chemical engineering, materials science, or applied physics elective courses selected from ChE 118, ChE 120, ChE/Ch 1552, ChE/Ch 164, ChE/Ch 165, APh 109, APh 114 ab, any MS course, or approved related courses.^{3,4}

e. Computational track: ACM/IDS 104, ChE 141, at least one course sequence from [Ch 121 ab; BE 163 & BE 191 a; ESE 101 & ESE 136; Ae 232 ab; or ChE 90 abc], and additional units from ChE 142 or approved courses in IDS, ACM, CS or related options.³

3. 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)
4. Passing grades must be earned in a total of 486 units, including courses listed above.

¹ The 9 units of Ec 11 or BEM 103 partially satisfy the Institute requirements in humanities and social sciences.

² Given in alternate years.

³ No more than 18 units of [ChE 90ab or ChE 80] 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.

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	-	-
ChE 15	Introduction to Chemical Engineering Computation	9	-	-

Ch/ChE 9	Chemical Synthesis and Characterization for Chemical Engineering	-	-	9
Ch 41 abc	Organic Chemistry	9	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	-	-
	Total	45	42	39

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, Ch, track courses, and electives 1	9	9	9
Ec 11, BEM 102, or BEM 103		9	-	-
	HSS electives	9	18	18
	Total	39	45	45

Fourth Year

ChE 126	Chemical Engineering Lab	9	-	-
	ChE, Ch, track courses, and electives 1	18	18	9
Ch 21 abc2	Physical Chemistry	9	9	9
	HSS electives	9	9	18
	Total	45	36	36

¹ See option requirements.

² Ch 24 can be substituted for Ch 21 b.

CHEMISTRY OPTION AND MINOR (Ch)

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, 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 energy and environment, molecular medicine, and nanomaterials. 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 the operation and control of manufacturing processes, and in management and development positions in the chemical industry.

A first-year general chemistry course is taken by all freshman 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. 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. Freshmen intending to major in chemistry are encouraged to take Ch 10 abc, which provides an introduction to research activities and opportunities in chemistry for undergraduates.

Beyond the freshman year, each student in the chemistry option, in consultation with his or her 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 his or her 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,

Ch 90, and, if taken during the first or second terms of the freshman year, Ch 4 ab, Ch 21 ab, and Ch 41 ab.

Ch Senior Thesis

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. At the time of registering for the first term of Ch 82, the candidate will submit a short (five-page) proposal delineating his/her 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 current status of the research work and any results obtained. Upon evidence of satisfactory effort, the student will be allowed to continue his/her 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. If the thesis is being completed during the spring quarter of the senior year, a draft of the thesis is to be submitted by Add Day.

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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.

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.

Ch Option Requirements

1. Ch 14, Ch 21ab, Ch 21 c or Ch 25, Ch 41abc, Ch 90, Ma 2, and Ph 2a. Ma 3 is recommended but not required. Students may make the following substitutions: For Ch14 (Ch/ESE175);

for Ch 21a (Ph 2b, Ph 12b, Ch 125a or Ph 125a); for Ch 21b (Ch 126); 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.

2. A minimum of five terms of laboratory work chosen from Ch 4ab, Ch 5ab, Ch 6ab, Ch 7, and Ch 15. One non-chemistry laboratory course may be used, chosen from MS 90, Ph 6 and Ph 7. One term of research, either 10 c (if taken freshman or sophomore 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 electives.
3. A minimum of five terms of advanced chemistry electives (which must total at least 45 units) taken for a letter grade from chemistry course offerings at the 100 and 200 level, 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.
4. Passing grades must be earned in the courses that constitute the approved program of study, including those listed above. None of the courses satisfying option requirements may be taken pass/fail.

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

		<i>Units per term</i>		
		<i>1st</i>	<i>2nd</i>	<i>3rd</i>
<i>Second Year</i>				
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 14	Chemical Equilibrium and Analysis	-	9	-
	Electives	18-21	18-27	18-21
	Total	45-48	36-45	45-48

Third Year

Ch 5 a	Advanced Techniques of Synthesis and Analysis	-	12	-
or Ch 5 b		9	-	-
Ch 15	Chemical Equilibrium and Analysis Laboratory	10	-	-
Ch 21 abc or Ch 21 ab, Ch 25	Physical Chemistry	9	9	9
Ch 90	Oral Presentation	-	3	-
Ch/ChE 91	Scientific Writing	-	-	3
	Electives	17-29	21-36	33-36
	Total	45-48	45-48	45-48

Fourth Year

Ch 6 a	Physical and Biophys. Chemistry Lab	-	9	-
or Ch 6 b		-	-	9
or Ch 7	Advanced Experim. Methods in Bioorganic Chemistry	-	-	9
	Electives	45-48	35-48	26-48
	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

	<i>Second Year</i>	<i>Third Year</i>	<i>Fourth Year</i>
<i>Inorganic Chemistry</i>	Ch 4 ab, Ch 5 a, Ch 41 abc, Ch 102, Ma 2 ab, Ph 2 ab, HSS elective, other elective	Ch 5 b, Ch 14, Ch 21 abc, Ch laboratory, Ch elective(s), Ch 80, Ch 90, Ch/ChE 91, HSS elective	Ch 6 a or 6 b, or Ch 15 Ch electives, Ch 80, HSS elective

<i>Chemical Physics</i>	Ch 4 ab, Ch 21 abc, Ch 6 ab, Ch 14, Ma 2 ab, Ph 2 ab, HSS elective	Ch laboratory, Ch 41 abc, Ch elective(s), Ch 80, Ch 90, ACM 95 abc, Ch/ChE 91, HSS elective	Ch 125 abc, Ch 15, Ch electives, Ch 80, HSS elective
<i>Organic Chemistry</i>	Ch 4 ab, Ch 5 a, Ch 41 abc, Ch 102, Ma 2 ab, Ph 2 ab, HSS elective, other elective	Ch 5 b or Ch 7, Ch 14, Ch 21 abc, Ch elective(s), Ch laboratory, Ch 80, Ch 90, Ch/ChE 91, HSS elective	Ch 6 a or Ch 6 b, Ch 15, Ch elec- tives, Ch 80, HSS elec- tive
<i>Biochemistry</i>	Ch 4 ab, Bi 10, Ch 41 abc, Bi 9, Ma 2 ab, Ph 2 ab, HSS elective	Ch laboratory, Ch 7, Ch 14, Ch 21 ab, Ch 25 (or Ch 21 bc), Ch 80 (or Bi 22), Ch 90, Ch/ChE 91, Bi/Ch 110, Bi/Ch 111, Bi 10	Ch 6 a or 6 b, Ch 15, Ch (Bi) electives, Ch 80 (or Bi 22), HSS elective

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 Ch4ab, Ch 5 ab, Ch 6 ab, Ch7 or Ch15. 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 his/her 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. Fulfillment of extended core requirements in Differential Equations (Ma 2 or equivalent); Probability and Statistics (Ma 3, Ge/ESE 118 or equivalent); Waves (Ph 2a, Ph 12a or equivalent), Thermodynamics and Statistical Mechanics (Ph 2c, Ph 12c or equivalent).
2. Demonstration of competency in computer programming or computer science by taking CS 1, CS 2, and one of BE 103 and CS 3 or by taking an approved alternative course, or by passing a placement exam administered by the computer science option.
3. Bi/CNS 162 and 9 units of laboratory courses taken from the following list: CS/CNS 171, CS/CNS 174, EE 45, EE/CS 53, EE 90, EE 91 ab, ME 72 ab, ME 50ab, BE 107, BE/EE/MedE 189 a, BE/CS 196a, Bi/BE 227, Bi/CNS/BE/NB 230.
4. ACM 95 ab, or Ma 108 abc, or Ma 109 abc.

5. SEC 10 and SEC 11, SEC 12, or SEC 13; or Bi/BE 24.
6. Bi 8, Bi 9, Bi/CNS/NB 150, Bi/CNS/ NB 157, Bi/CNS/NB 164.
7. Choose five from the following list: EE 111, CS/CNS/EE 156 ab, CS/CNS/EE 155, CS 159, CNS/Bi/EE/CS/NB 186, CNS/ Bi/Ph/CS/NB 187, BE/CS/CNS/Bi 191a, BE 150, IDS/ACM/ CS 157.
8. 45 units of electives chosen from either advanced EAS courses or advanced science courses offered by BBE, CCE, GPS, or PMA divisions.

CNS Typical Course Schedule

		<i>Units per term</i>		
		<i>1st</i>	<i>2nd</i>	<i>3rd</i>
<i>First Year</i>				
CS 1	Introduction to Computer Programming	9	-	-
CS 2	Introduction to Programming Methods	-	9	-
	Freshman Humanities	9	9	9
	Freshman Core	27	27	27
	Total	45	45	42
<i>Second Year</i>				
Ph 2 ac	Waves, Statistical Mechanics	9	-	9
Ma 2, 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
Bi 150	Introduction to Neuroscience	-	-	10
	HSS Electives	9	9	9
	Electives	9	9	-
	Total	48	39	49
<i>Third Year</i>				
BE 103	Data Analysis in Biological Sciences	12	-	-

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	18	18
	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)

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 http://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. Courses may be used to simultaneously fulfill requirements in both options. However, it is required that students have at least 72 units of computer science courses numbered 80abc, 81abc, or 114 and above that are not simultaneously used for fulfilling a requirement of the second option, i.e., requirement 4 in computer science 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 his/her 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; CS 2; CS 4; CS 11,
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.
 - c. Any of the following three-quarter sequences. Each of the sequences is expected to be available (nearly) yearly.
 - i. Databases: CS/IDS 121, CS 122, CS 123.
 - ii. A graphics project class (CS 174, CS 176, or CS ACM 177 b) as well as two other CS 17x courses.
 - iii. sLearning & 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.
 - iv. Networking & Distributed Systems: CS 141, CS/EE 145, or EE/CS 147 combined with two courses chosen from CS/IDS 142, CS/EE/IDS 143, and CMS/CS/EE/IDS 144.
 - v. 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.
 - vi. Robotics: At least three courses chosen from ME 115 ab, ME/CS/EE 133 B, ME/CS/EE 134, EE/CNS/CS 148, CNS/Bi/EE/CS/NB 186.
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 122, CS 124, CMS/CS/IDS 139, CS/IDS 142, CS/EE/IDS 143, CS/IDS 150 a, or CS 151.

5. Mathematical fundamentals. Ma 2/102; Ma 3/103; Ma/CS 6a or Ma 121a.
6. Communication fundamentals. SEC 10; SEC 11, SEC 12, or SEC 13.
7. Scientific core electives. 18 units selected from the following courses: Bi 8, Bi 9, Ch 21 abc, Ch 24, Ch 25, Ch 41 abc, Ph 2 abc, or Ph 12 abc. Advanced 100+ courses in Ay, Bi, BE, Ch, CNS, Ge, MedE, or Ph with 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, 36 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

		<i>Units per term</i>		
		<i>1st</i>	<i>2nd</i>	<i>3rd</i>
<i>Second Year</i>				
	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	-
Ma/CS 6 a	Intro. to Discrete Math	9	-	-
CS 21	Decidability and Tractability	-	9	-
CS 3	Intro. to Software Design	-	-	9
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
E 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 freshman 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*Computer Science Minor*

1. CS fundamentals. CS 1; CS 2; and CS 11.
2. Mathematical fundamentals. Ma 2; Ma 3; 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 his/her 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

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 231 or CDS 232
- Complete nine additional units in CDS courses, chosen from CDS 110, CDS 112, CDS 131, CDS 141, CDS 232, CDS 233, CDS 242, CDS 243, CDS 244.
- 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)

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 sufficiently flexible so that students can combine their pursuit of economics with studies in engineering, mathematics, or 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. 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 105 or Ec 135.
5. Macroeconomics and growth: one of Ec/SS 129, 130, or Ec 140.
6. Ma 3.
7. 45 additional units of advanced economics and social sci-

ence 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.

8. 45 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.
9. Passing grades must be earned in a total of 486 units, including all courses used to satisfy the above requirements.
10. 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

		<i>Units per term</i>		
		<i>1st</i>	<i>2nd</i>	<i>3rd</i>
<i>Second Year</i>				
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	36	36	45
<i>Third Year</i>				
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)

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 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 freshman-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; Introduction to Digital Logic and Embedded Systems EE/CS 10ab; semiconductor sensors and actuators, EE 40; the theory and laboratory practice of analog circuits, EE 45; and then a course on feedback control systems, EE 113 or CDS 110. The junior year

features the fundamentals of signals and systems and digital signal processing, EE 111; random variables and stochastic processes, ACM/EE/IDS 116; electromagnetic engineering, EE 151; and an analog electronics laboratory, EE 90. In the senior year, the student will be asked to demonstrate his or her ability to formulate and carry out a design project through independent research or either a senior thesis, EE 80 abc, or two courses selected from the senior project design laboratory, EE 91 ab, and CS/EE/ME 75 c. In addition, the student throughout his/her studies and especially in the senior year, will have a significant opportunity to take elective courses that will allow him/her to explore earlier topics in depth, or to investigate topics that have not been covered previously. (See the “suggested electives” section, page 281.)

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 his/her 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. 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 elective requirement in EE. To qualify for an EE degree, the student would need to complete all option requirements.

EE Option Requirements

1. Ma 2, Ma 3, Ph 2 abc. Ph 12 abc can replace Ph 2 abc.
2. APh 109 or a sequence consisting of APh/EE 23 and APh/EE 24
3. EE 2, SEC 10, one of SEC 11-13, EE/CS 10ab, EE 40, 44, 45, 90, 111, 151, EE/CS/IDS 160 and ACM/EE/IDS 116.
4. ACM 95 ab.
5. EE 113 or CDS 110.
6. One term of EE 91.
7. EE 80 abc, or a sequence consisting of CS/EE/IDS 143, CS/EE 144, 145, or a sequence consisting of BE/EE/MedE 189 a, or one course selected from an additional term of EE 91,

EE/CS 119 c, and CS/EE/ME 75 c (note that CS/EE/ME 75 ab does not satisfy this requirement).

8. In addition to the above courses, 45 units selected from any EE course numbered over 100, or any cross-listed courses numbered over 100 that include EE in the listing. These units must also include at least one course taken for two quarters (an ab sequence). Included in these units must be at least one of EE 112, EE/Ma/CS 126a, or EE/Ma/CS/IDS 127.
9. Passing grades must be earned in a total of 486 units, including courses listed above. Courses used to satisfy requirements 1 through 8 must be taken for grades, unless they are only offered pass/fail.

EE Typical Course Schedule¹

			<i>Units per term</i>		
			<i>1st</i>	<i>2nd</i>	<i>3rd</i>
Second Year – Schedule 1					
Ph 2 abc	Sophomore Physics		9	9	9
Ma 2, Ma 3	Sophomore Mathematics		9	9	-
	HSS electives ¹		9	9	9
EE 40	Physics of Electrical Engineering		-	-	9
EE 44	Deterministic Analysis of Systems and Circuits		12	-	-
EE 45	Electronics Systems and Laboratory		-	12	-
EE 113	Feedback and Control Systems		-	-	9
EE/CS 10 ab	Introduction to Digital Logic and Embedded Systems		-	6	6
	Electives		9	-	-
	Total		48	45	42

Second Year – Schedule 2

Ph 2 abc	Sophomore Physics		9	9	9
Ma 2, Ma 3	Sophomore Mathematics		9	9	-

	HSS electives	9	9	9
EE 40	Physics of Electrical Engineering	-	-	9
EE 44	Deterministic Analysis of Systems and Circuits	12	-	-
EE 45	Electronics Systems and Laboratory	-	12	-
EE 113	Feedback and Control Circuits	-	-	9
ACM 95 ab	Intro. Methods of Applied Math.	-	12	12
	Electives	9	-	-
	Total	48	51	48

Third Year – Schedule 1

SEC 10	Technical Seminar Presentations	3	-	-
one of SEC 11-13	Written Communication	-	3	-
ACM 95 ab	Intro. Methods of Applied Math.	-	12	12
	HSS electives ¹	9	9	9
EE 151	Electromagnetic Engineering	-	-	9
EE 111	Signals, Systems, and Transforms	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	-	-
	Electives	9	9	9
	Total	39	42	48

Third Year – Schedule 2

SEC 10	Technical Seminar Presentation	3	-	-
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one of SEC 11-13	Written Communication	-	3	-
EE/CS 10 ab	Introduction to Digital Logic and Embedded Systems	-	6	6
	HSS electives	9	9	9
EE 151	Electromagnetic Engi- neering	-	-	9
EE 111	Signals, Systems, and Transforms	9	-	-
EE/CS/IDS 160	Fundamentals of Infor- mation Transmission and Storage	-	9	-
EE 90	Analog Electronics Project Lab	-	-	9
ACM/EE/IDS 116	Introduction to Probabili- ty Models	9	-	-
	Electives	9	18	9
	Total	39	45	42

Fourth Year (for project)

	HSS electives ¹	9	9	9
EE 91 ab ²	Experimental Projects in Electronic Circuits	9	-	-
	EE electives	9	9	9
	Electives	9	18	18
		36	36	36

Fourth Year (for thesis)

	HSS electives ¹	9	9	9
EE 91 ab ²	Experimental Projects in Electronic Circuits	9	-	-
EE 80	Senior Thesis	9	9	9
	EE electives	9	9	9
	Electives	3	9	9
	Total	39	36	36

¹ See Institute requirements for specific rules regarding humanities and social sciences.

² See option requirements 6 and 7.

EE Suggested Electives

Suggested elective courses for the second, third, and fourth year for various specializations within electrical engineering are given below. Students interested in other areas of specialization or interdisciplinary areas are encouraged to develop their own elective program in consultation with their faculty adviser.

Bioengineering

Second Year: Bi 9, Bi 10, APh 17 abc.

Third and Fourth Year: Bi/Ch 110, EE/MedE 114, BE 141, EE/BE/MedE 185, CNS/Bi/EE/CS/NB 186, BE/EE/MedE 189 ab.

Communications and Signal Processing

Second Year: Selected from APh 17 abc, APh/EE 23, APh/EE 24,

Third and Fourth Year: EE 112, EE/Ma/CS 126 ab, EE/Ma/CS/IDS 127 ab, EE 128 ab, 164, EE/CS/IDS 160, 167, EE/CS 161, EE/APh 131, APh/EE 130, 132, Ma 112 a.

Control

Second Year: APh 17 abc.

Third and Fourth Year: CDS 110, and selections from EE 112, EE 128 ab, EE 164.

Electronic Circuits

Second Year: EE 113, CDS 101, APh/EE 183.

Third and Fourth Year: EE/MedE 114 ab, 124, EE 110abc, 153, EE/CS 119 ab, EE/CS/MedE 125, and selections from EE 112, CS 185 ab, EE/APh 180, EE/CS 119, EE/CS/IDS 160, EE 128 ab.

Microwave and Radio Engineering

Second Year: APh/EE 23, APh/EE 24, APh 17 abc.

Third and Fourth Year: EE 153, EE/Ae 157 ab, EE/MedE 114 ab, EE/APh 131, APh/EE 130, 132, APh/EE 183.

Optoelectronics

Second Year: APh/EE 23, APh/EE 24, APh 17 abc.

Third and Fourth Year: APh/EE 130, 132, APh 105 abc, APh 114 abc, APh/EE 183, APh 190 abc, EE/APh 131, EE 153.

Solid-State Electronics and Devices

Second Year: APh 17 abc.

Third and Fourth Year: APh/EE 183, and selections from APh 105 abc, APh 114 ab, EE 153, EE/BE/MedE 185, EE/MedE 187.

Robotics

ME/CS/EE 134 and two more courses from the following list:

ME/CS/EE 133 ab, EE/CNS/CS 148, CNS/Bi/EE/CS/NB 186, CDS 131, CMS/CS/CNS/EE/IDS 155.

ENGINEERING AND APPLIED SCIENCE OPTION (EAS)

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 freshman 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, Ge/ESE 118 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.
 3. 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.
 4. a. 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 ab, MS 90, MS 125, ME 72 ab, ME 50 ab, ME 90 bc; and
b. 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 freshman laboratory credit is allowed.
 5. ACM 95 ab or Ma 108 abc or Ma 109 abc. None of these course sequences may be taken pass/fail.
 6. SEC 10 or equivalent; one of SEC 11, SEC 12, or SEC 13 or equivalent.
 7. 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 chosen from EE 91 ab and EE/CS 53. The student must submit a written proposal justifying their course selections, and obtain the approval of, the EAS optio representative by the end of the third term of the sophomore year.
 8. At least 117 units of EAS courses not including those used to satisfy requirements 4, 5, and 6 above.
 9. The customized schedule of requirements described in 7 shall include a major design experience.
 10. Passing grades must be earned in at least 486 units, including those listed in requirements 1–8 above.

ENGLISH OPTION AND MINOR (En)

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 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, which must include at least one course in each of the following areas: British literature, American literature, and literature before 1850. 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, 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 freshman humanities course in English when taken in the first two quarters of the freshman 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. 27 of these units must include one course in British

literature, one course in American literature, and one course in literature before 1850 (En 103, 110, 113, 118, 121, 122, 125, 127, 129, 188, 189, 190, and En/H 193, 197). Courses cannot be counted twice in meeting these distribution requirements. Up to nine units of freshman humanities in English (courses cross-listed Hum/En numbered 50 or below) and/or up to nine units of En 98 may be substituted for up to 18 of the remaining 54 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 54 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.

Courses used to complete the English option under categories 1 and 2 above 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.

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 freshman 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 freshman humanities course in English when taken in the first two quarters of the freshman 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 freshman humanities in English (courses cross-listed Hum/En numbered 50 or below) may be substituted 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.

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 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 (GPS)

(Geology, Geobiology, Geochemistry, Geophysics, Planetary Science)

The aim of this 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 firsthand experience with geological phenomena that can never be satisfactorily grasped or understood solely from classroom or laboratory treatment. Options 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 and the other planets are likely to find their niche in these options, especially if they enjoy grappling with complex problems involving many variables. Most students majoring in the earth and planetary sciences now pursue further training at the graduate level.

Under the geobiology option, a student can be associated with either the biology or the GPS division. This association formally will only affect which course the students elect to satisfy the Institute-wide oral presentation requirement; all other geobiology option requirements are independent of GPS or biology affiliation. In practice, however, we expect that students' affiliation with one division or another will significantly shape their choice of elective courses.

For students beginning their junior year, it is possible to complete the requirements for geochemistry, geophysics, and planetary science options within two years, but there are benefits from starting with the Ge 11 sequence in the sophomore year. Because Ge 120 ab may not be offered every year, students in the geology option 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.

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 Option Requirements

Geology Option Requirements

1. Ge 11 ab, Ge/Ay 11 c or Ge 11 d¹, and any writing class and oral presentation class that satisfies the Institute scientific requirements².
2. Ma 2 and one choice from: Ma 3, Ge/ESE 118, or Ge/Ay 117.
3. Ph 2 a or Ph 12, a plus an additional quarter of sophomore-level physics (Ph 2 b, 2 c, 12 b, or 12 c).
4. Either ACM 95 ab or the combination of a full-year chemistry sequence (Ch 41 abc or Ch 21 abc).
5. Ge 106, 114 ab, 115 ab, 120 ab³.
6. Ge 111 ab or Ge 11 d.
7. Ge 112 or Ge 125.
8. Elective courses in Ge or cross-listed with Ge to bring the total option units up to 210 (selected in consultation with adviser and approved by the option representative).

¹ No class may be used to simultaneously satisfy more than one of these requirements.

² For example, SEC 10 and one of SEC 11, SEC 12, SEC 13, or can be satisfied by En/Wr 84.

³ If Ge 120b is not offered, a suitable 3-5 week field camp may be substituted.

GPS Typical Course Schedules

		Units per term		
		1st	2nd	3rd

Second Year

Ma 2 & 3	Sophomore mathematics	9	9	-
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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

Ge 120 b	Field Geology Camp	-	-	15
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Third year

ACM 95 ab	Intro. Methods of Applied Math.	-	12	12
Ge 112	Sedimentology and Stratigraphy	12	-	-
Ge 114 ab	Mineralogy	12	-	-
Ge 115 a	Petrology and Petrography	-	9	-
Ge 111 ab	Applied Geophysics	-	6	9
	HSS electives	9	9	9
	Total	33	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 Option Requirements

1. Ge 11 abc.
2. Bi 8, 9.
3. Ma 2 and one course in statistics and data analysis (Ma 3, Bi/CNS/NB 195, Ge/Ay 117, or Ge/ESE 118).
4. Two quarters of sophomore-level physics (Ph2a, b, c, or 12a, b, or c).
5. Ch 41 abc and Bi/Ch 110.
6. Any writing class that satisfies the Institute scientific writing requirement ¹; or Bi 24.

7. At least 9 units of laboratory instruction from: Bi 10, Ch 7, Ch 8, Ch 15, Ge 116, or Ge 120ab².
8. Any six courses from the geobiology core: Bi 117, Bi 122, ESE/Bi 166, ESE/ Bi 168, Ge/ESE/Bi 178, Ge 112, Ge/ESE 143, or Ge 124 ab.
9. 27 units of geobiology electives in geology, biology, chemistry, and/or environmental engineering to be chosen in consultation with adviser³.

¹For example, one of SEC 11, SEC 12, SEC 13 or En/Wr 84; with the approval of their adviser, students may also petition to do independent writing with a faculty member under Ge 40.

²May also be satisfied by units from other courses that have a laboratory component, or substitute thesis research or independent laboratory research, all with approval of option representative.

³May include any courses listed above that are not being used to fulfill a separate requirement.

		<i>Units per term</i>		
		<i>1st</i>	<i>2nd</i>	<i>3rd</i>
<i>Second Year</i>				
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
<i>Third Year</i>				
Bi/Ch 110	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 Option Requirements¹

1. Ge 11 ab, Ge/Ay 11 c or Ge 11 d, Ge 109, and a science writing course.²
2. Ma 2 and one choice from: Ma 3, Ge/ESE 118, Ge/Ay 117, Ph 2c, or Ch 21c.
3. Ph 2 a or Ph 12 a plus an additional quarter of sophomore-level physics (Ph 2 b, Ph 2 c, Ph 12 b, or Ph 12 c).
4. Either ACM 95 ab or the combination of a full-year chemistry sequence (Ch 21 abc or Ch 41 abc) plus Ge/ESE 118.
5. Three courses from the list below:
Ge 114 ab (counts as one course), Ge 116, Ge 140 a, Ge 140 b, Ge/ESE 140 c, Ch 21 a, Ch 41 a, ESE/Ge/Ch 171, Ge/ESE 143, Ge/ESE 149.
6. A total of 105 units from this and item 5 that include at least four courses in the Ge-option:
Ch electives: Ch 4 a, b, Ch 5 a, b, Ch 6 a, b, Ch 7, Ch 8, Ch/ChE 9, Ch 14, Ch 15, Ch 21 b, c, Ch 41 b, c, Ch 102.
7. *ChE electives:* ChE 63 a, b. *ESE electives:* ESE 103, Ge/ESE 154, ESE/Ge/Ch 172, ESE/Ch 175, ESE/Ch 176.
Ge electives: Ge 40, Ge 106, Ge 112, Ge 115 a, b, Ge 120 a, b, Ge/Ch 127, Ge/Ch 128, Ge/Ay 132, Ge 191, Ge 212, Ge 214, Ge 215.
APh electives: APh 17 a, b, c.
MS electives: MS 105, MS 115, MS 125, MS 131, MS 133, MS 142, MS/ME 161

¹ No class may be used to simultaneously satisfy more than one of these requirements.

² For example, SEC 11, SEC 12, SEC 13, or En/Wr 84.

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
		27	39	39

Fourth Year

	HSS electives	9	9	9
	Geochemistry electives	9	9	9
	Total	18	18	18

Geophysics Option Requirements

1. Ge 11 a, Ge 11 b or Ge 11/Ay c, SEC 10 and a science writing course.¹
2. Ge 111 ab, Ge 11 d
3. Ph 2 a or Ph 12 a, Ph 2b or 12b, and one of the following: Ph 2c, Ph 12c, ME 11a, APh 17a, Ch 21c, Ch 25.
4. Ma 2
5. One of Ma 3, Ge/Ay 117, Ge/ESE 118
6. ACM 95 ab
7. 36 units of advanced science courses selected in consultation with adviser and approved by the option representative. Appropriate choices include (but are not limited to): up to 18

units of Me 11 and 12, ME 65, 66, AM 125 abc, Ae/Ge/ME 160, Ph 106 abc, MS 115, MS 133, MS/ME/MedE 116.

8. 36 units of geophysics electives (selected in consultation with adviser and approved by the option representative). Appropriate choices include (but are not limited to): up to 9 units of Ge 40 and Ge 41abc, Ge 161–168, Ge 261, Ge 263, ME/Ge/Ae 266ab.

¹ For example, SEC 11, SEC 12, SEC 13, or En/Wr 84.

		<i>Units per term</i>		
		<i>1st</i>	<i>2nd</i>	<i>3rd</i>
<i>Second Year</i>				
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
		<hr/>	<hr/>	<hr/>
		36	36	33
<i>Third Year</i>				
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
<i>Fourth Year</i>				
	Geophysics electives	18	18	9
	HSS electives	9	9	9
Total		27	27	18

Planetary Science Option Requirements

- Ma 2 and one of Ma 3, Ge/Ay 117, or Ge/ESE 118.
- Ph2 a or 12 a, Ph 2 b or 12 b, and one of the following: Ph 2 c, Ph 12 c, APh 17 a, Ch 21 c, Ch 25, ME 11 a.

3. Ge 11 ab, Ge/Ay 11 c, 3 units of oral presentation (SEC 10 or 3 units of Ge 109, including an oral presentation at planetary sciences seminar), and a science writing course.¹
4. ACM 95 ab.
5. 45 units of advanced science courses selected in consultation with adviser and planetary science option representatives. Appropriate choices include (but are not limited to): Ae/APh/CE/ME 101 abc, Ae/Ge/ME 160 ab, Ch 21 abc, Ph 101, 106 abc, 125 abc, Ge/ESE 118, ME 12 abc, APh 17 abc, Ay 20, 21, 101, 102, ChE 63 ab, Ch 6 ab, CS 1-3, Ma 112 ab, ME 11 abc, 65, 66, AM 125 abc.
6. 63 units selected from Ge 11 d, Ge 40, 41, 102, Ge/Ay 117, Ge/Ch 128, Ge 131, Ge/Ay 132, Ge/Ay 133, Ge/Ay 137, Ge/Ay 159, ESE 101-103, Ge/ESE 150, Ge 151, Ge/EE/ESE 157 c, ESE 130, Ge/ESE 139.

¹ For example, SEC 11, SEC 12, SEC 13, or En/Wr 84.

		<i>Units per term</i>		
		<i>1st</i>	<i>2nd</i>	<i>3rd</i>
<i>Second Year</i>				
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
<i>Third Year</i>				
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
<i>Fourth Year</i>				
	HSS electives	9	9	9
	Planetary science	9	9	9

Additional science and engineering	9	9	9
Total	27	27	27

GPS Division Minor Requirements

The minors in the GPS Division are intended for non-GPS undergraduates to supplement a major degree with knowledge of earth and planetary science. Students may complete a minor in either Geobiology, Geochemistry, Geology, Geophysics, Planetary Sciences or a general GPS minor, and will have the phrase "minor in [the appropriate option]" added to their transcript. Any student interested in a minor in GPS is urged to contact the appropriate option representative in the division.

1. Ge 11 a and Ge 11 b.
2. One of Ge/Ay 11 c or Ge 11 d.
3. 27 units of 100-level or higher GPS courses, excluding Ge 109, which must be approved by the appropriate option representative.

HISTORY OPTION AND MINOR (H)

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 freshman 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 freshman humanities course in history when taken in the first two quarters of the freshman 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 his or her 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. He or she 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 his or her 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 he or she comes to Caltech will be well advised to take a freshman humanities course in history (courses cross-listed Hum/H numbered 50 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 his or her 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 freshman humanities in history (courses cross-listed Hum/H numbered 50 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 freshman 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 freshman humanities course in history when taken in the first two quarters of the freshman 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 freshman humanities in history (courses cross listed Hum/H numbered 50 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)

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/PI 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/PI 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 freshman humanities courses. Students making the decision to follow this option in their sophomore year should take Hum/H/HPS 18 and HPS/PI 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/SS 129, Ec/SS 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 freshman humanities courses.

		<i>Units per term</i>		
		<i>1st</i>	<i>2nd</i>	<i>3rd</i>
<i>Second Year</i>				
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/SS 129, Ec/SS 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. Freshman 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 com-

pleting 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 (IDS)

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; CS 2; and CS 38.
2. *Mathematical Fundamentals*. Ma 2; Ma 3; Ma 108a; and Ma/CS 6ab or Ma 121ab. The analytical tracks of Ma1bc are required.
3. *Scientific Fundamentals*. 18 units selected from the following courses Bi 8, Bi 9, 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 administrator, but cannot simultaneously be used to satisfy the "Applications of Data Science" requirement or the "Advanced Electives" requirement.
4. *Communication Fundamentals*. SEC 10; SEC 11, SEC 12, or SEC 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.
 - f. Information Theory: EE/IDS 160
6. *Applications Electives*. At least 18 units from the following list: Ay 119, BE/Bi 103 ab, Bi/BE/CS 183, BEM/Ec 150, CNS/Bi/EE/CS/NB 186, ME/CS/EE 134, EE/CNS/CS 148, Ec/SS 124, ESE 136, Fs/Ay 3, Fs/Ph 4, Ge/Ay 117, Ge 165, HPS/PI/CS 110, SS 228. Other courses that include applications of data science may be substituted with approval from the option coordinator. 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. 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 his/her 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

		<i>Units per term</i>		
		<i>1st</i>	<i>2nd</i>	<i>3rd</i>
<i>Second Year</i>				
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	-
SEC 11, SEC 12, or SEC 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: Justin Bois, Fernando Brandao, Shuki Bruck, George Djorgovski, Laura Doval, Frederick Eberhardt, Federico Echenique, Babak Hassibi, Jonathan Katz, Victoria Kostina, Heather Knutson, Tom Miller, Pietro Perona, Antonio Rangel, Mark Simons, Omer Tamuz, Andrew Thompson, Matt Thomson, Victor Tsai, David Van Valen, 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; CS2; and CS38.
2. *Mathematics Fundamentals*. Ma 3, Ma/CS 6a or Ma 121a.
3. *Information and Data Science Core Requirements*.
 - a. Probability: ACM/EE/IDS 116.
 - b. Linear Algebra: ACM/IDS 104.
 - 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
4. *Applications of Data Science*. At least 9 units from the following list: Ay 119, BE/Bi 103 ab, Bi/CNS/NB 153, Bi/CNS/NB 162, Bi/BE/CS 183, BEM/EC 150, CNS/Bi/EE/CS/NB 186, ME/CS/EE 134, EE/CNS/CS 148, Ec/SS 124, ESE 136, Fs/Ay 3, Fs/Ph 4, Ge/Ay 117, Ge 165, HPS/PI/CS 110, SS 228. Other courses that include applications of data science may be substituted with approval from the option coordinator.
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. 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 (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 freshman 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 (ISP)

The Interdisciplinary Studies Program (ISP) is an undergraduate option that allows the student to create his or her 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 his or her 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 his or her 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)

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 freshman 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, Ge/ESE 118 or equivalent); Waves (Ph 2a, Ph 12a or equivalent), Quantum Mechanics (Ph 2b, Ph 12b, Ch 21a or equivalent); Thermodynamics and Statistical Mechanics (Ph 2c, Ph 12c 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. 9 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 45, , EE/CS 53, EE 90, EE 91 ab, ME 72 ab, ME 50ab, MS 121, MS/APh 122, MS 125, MS 142.
4. 9 units of additional laboratory courses either from the list above or from EAS courses with the word "laboratory" in the title, but excluding those courses for which freshman laboratory credit is allowed.
5. ACM/IDS 104 and ACM 95 ab, or Ma 108 abc, or Ma 109 abc.
6. SEC 10 or equivalent; SEC 11, SEC 12, SEC 13 or equivalent.
7. APh 17 ab or ChE 63 ab or APh/MS 105 ab.
8. MS 115 and MS/ME/MedE 116 and MS 90 (or other appropriate laboratory in MS).
9. At least 45 of additional units from the following list of restricted electives: ACM/IDS 104, Ae/AM/CE/ME 102 abc, APh/MS 105 abc, APh 114 abc, APh/EE 130, APh/EE 183, Ch 21 abc, Ch 120 ab, Ch 121 ab, Ch 125 abc, 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, MS 142, Ph 125 abc. Substitution of courses may be approved at the discretion of the option representative.
10. Senior thesis MS 78 abc.

Passing grades must be earned in at least 486 units, including those listed in requirements 1–10 above.

MS Typical Course Schedule

		<i>Units per term</i>		
		<i>1st</i>	<i>2nd</i>	<i>3rd</i>
<i>Second Year</i>				
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
<i>Third Year</i>				
ACM/IDS 104	Applied Linear Algebra	9	-	-
ACM 95 ab	Intro. Methods of Applied Math.	-	12	12
APh 105abc	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
<i>Fourth Year</i>				
SEC 10	Technical Seminar Presentation	3	-	-

SEC 11, SEC 12, or SEC 13	Written Communication	-	3	-
MS 78abc	Senior Thesis	9	9	9
	HSS Electives	9	9	9
	Lab Class	9	-	-
	Restricted Electives	18	18	18
	Total	48	39	36

MATHEMATICS OPTION (Ma)

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.

Freshmen 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 completed during fall or winter of freshman year or when 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

		<i>Units per term</i>		
		<i>1st</i>	<i>2nd</i>	<i>3rd</i>
<i>Second Year</i>				
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
<i>Third Year</i>				
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.

MECHANICAL ENGINEERING OPTION (ME)

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 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 at 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 option is accredited by the Engineering Accreditation Commission of ABET, 111 Market Place, Suite 1050, Baltimore, MD 21202-4012, (410) 347-7700.

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 95ab, and 9 units selected from Ma 3, Ma 6a, ACM 104, or other ACM courses numbered 100 and above.
3. Physics: 18 units selected from Ph 2abc.
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 (BE / Bi 103 and Ge/ESE 118 are acceptable substitutions for 2019-20), 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 must complete at least 18 units distributed amongst all three quarters

** These courses are selected in consultation with the student's adviser and 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	-	-
	Computing Elective	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	46	43	39

Third Year

	Physics Electives	9	-	9
ME 50 ab	Exp. and Modeling in ME	-	9	9
ME 40	Dimensional and data analyses in engineering	9	-	-
	Capstone Design	9	9	-

SEC 10	Technical Seminar Presentation	-	-	3
SEC 11, SEC 12, or SEC 13	Written Communication	3	-	-
	HSS Electives	9	18	9
	Total	39	36	30

Fourth Year

	Math Electives	9	-	-
	Advanced ME electives	18	18	9
	HSS electives	9	9	9
	Total	36	27	18

PHILOSOPHY OPTION AND MINOR (PI)

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 PI 90 ab, to be taken in any two consecutive terms in the senior year. The 99 units may include nine units of freshman humanities in philosophy (courses cross-listed Hum/PI numbered 50 or below), nine units of PI 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 freshman humanities course in philosophy. From the sophomore year onward, they should plan on taking one philosophy course per term, culminating in two terms of PI 90 ab in the senior year. Students in PI 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 PI 98 and courses taken during the first two quarters of the freshman year, all courses to be counted toward the philosophy option must be taken for grades unless special permission is granted by the option representative.

PI Option Requirements

1. PI 90 ab.
2. 63 units of advanced philosophy courses, numbered 99 or above. Up to nine units of freshman humanities in philosophy (courses cross-listed Hum/PI numbered 50 or below) and/or up to nine units of PI 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.)

er. 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.

PI 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 PI 98 and courses taken during the first two semesters of freshman 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 PI 98 may be substituted for any nine units of the 72 required for the minor.
3. Nine units of freshman humanities in philosophy (courses cross-listed Hum/PI numbered 50 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)

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

el 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 choice of laboratory course 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.

1. Ph 3.¹
2. Ma 2 and Ma 3.
3. Ph 12 abc.
4. Ph 6.
5. Ph 7 or APh/EE 24.²
6. 27 units of Ph 78 (experimental), or 18 units of Ph 77, 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 70.³
8. Ph 106 ab.
9. Ph 125 ab.
10. Ph 127 a.
11. Ph 21 or Ph 22 or one term of Ph 121 abc or Ay 190.

¹ Other laboratory courses may be substituted for the Ph 3 requirement, including Ph 5, Ph 8 bc, or APh 9 a.

² APh 23 is a prerequisite for APh/EE 24 and can be used towards the advanced physics elective requirement.

³ 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, ACM 95, ACM 101, APh/EE 23, Ma 5, Ma 108, or up to 10 units for Ay 20 – 21. Nine units towards the 72 unit requirement will be given for taking three terms of Ph 77. Students are encouraged to take ACM 95 as part of this requirement.

The pass/fail option cannot be exercised for any courses used for this requirement with the exception of ACM 95 and courses that do not offer grades. Not more than 36 units of Ph courses numbered 200 or above taken on a pass/fail basis may apply toward this requirement. No more than 18 units of Ph 171-172 may apply toward this requirement without permission from the Undergraduate Option Representative. Additionally, Ph 171-172 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.
3. Passing grades must be earned in a total of 486 units, including the courses listed above.

Ph Typical Course Schedule

		<i>Units per term</i>		
		<i>1st</i>	<i>2nd</i>	<i>3rd</i>
<i>Second Year</i>				
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
<i>Third Year</i>				
Ph 106 ab	Topics in Classical Physics	9	9	-
Ph 121 abc	Advanced Computational Physics	6	6	6

Ph 125 ab	Quantum Mechanics	9	9	-
Ph 70	Oral & Written Communication	6	-	[6]
	HSS and/or PE Electives	9	9	9
	Advanced Physics Electives	9	12	33 [27]
	Total	48	45	48

Fourth Year

Ph 77 abc	Advanced Physics Laboratory	9	9	-
Ph 127 a	Statistical Physics	9	-	-
	Advanced Physics Electives	9	9	18
	Electives	9	18	18
	HSS and/or PE Electives	9	9	9
	Total	45	45	45

POLITICAL SCIENCE OPTION (PS)

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, 130, 135, PS/SS 139, PS 141ab, Law/PS/H 148 ab, or PS/ Ec 172.
3. PS 99 ab.
4. Ma 3.
5. 36 additional units in advanced political science, economics, law, social science, psychology, or history.
6. 36 additional units in advanced social science, science, engineering, or mathematics.
7. Passing grades must be earned in a total of 486 units, including all courses used to satisfy the above requirements.

PS Typical Course Schedule

		<i>Units per term</i>		
		<i>1st</i>	<i>2nd</i>	<i>3rd</i>
<i>Second Year</i>				
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	48	45
<i>Third Year</i>				
	Political Science Electives ¹	18	18	18
	Electives	27	27	27
	Total	48	45	45
<i>Fourth Year</i>				
PS 99 ab	Research in Political Science	-	9	9
	Political Science Electives ¹	18	18	18

Electives	27	18	18
Total	45	45	45

¹ See option requirements 2, 5, and 6.

STRUCTURAL MECHANICS MINOR (SM)

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.