

Information for Graduate Students



The Institute offers graduate degrees of Master of Science and Doctor of Philosophy, and in special cases the degree of Engineer.

The Institute is organized into six academic divisions: Biology and Biological Engineering; Chemistry and Chemical Engineering; Engineering and Applied Science; Geological and Planetary Sciences; the Humanities and Social Sciences; and Physics, Mathematics and Astronomy.

Graduate work at the Institute is further organized into graduate options, which are supervised by those professors whose interests and research are closely related to the area of the option, within the administrative jurisdiction of one or more of the divisions.

A faculty member serves as the representative for an option. The option representative provides consultation on academic programs, degree requirements, financial aid, etc., and provides general supervision to graduate students in the option. The Committee on Graduate Studies, which includes the option representatives, elected members of the faculty at large, and graduate students appointed by the Graduate Student Council, exercises supervision over the scholastic requirements established by the faculty for all advanced degrees, provides policy guidance to the Dean of Graduate Studies, and certifies all candidates for graduate degrees to the faculty for their approval. A list of the option representatives for the current academic year can be found at www.registrar.caltech.edu/academics/grad_option_reps.

GRADUATE POLICIES AND PROCEDURES

ADMISSION TO GRADUATE STANDING

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Application

An application for admission should be completed online through the Graduate Office at www.gradoffice.caltech.edu/admissions. Admission is granted once a year to a limited number of students of superior ability. Completed applications are due between December 1 and January 1, for enrollment at the beginning of the fall term of the following year. Please refer to the Graduate Office website for specific deadlines. The graduate program thrives on exceptional individuals from a diverse range of backgrounds and experiences, and we highly encourage applications from members of groups underrepresented in science and engineering. Graduate admission is covered by Caltech's Nondiscrimination Policy. For more information on this policy, please refer to page 92. Applicants will automatically be considered for financial aid; no additional application is required.

To be admitted to graduate standing, an applicant must have received a bachelor's degree, or the equivalent, representing the completion of an undergraduate course in science or engineering related to one of the options offered by the Institute. Applicants

must, moreover, have attained a scholastic record and provide recommendations to indicate the fitness to pursue, with distinction, advanced study and research.

Required Tests

Graduate Record Examination (GRE) verbal, quantitative, and writing scores and advanced subject GRE scores may be optional, recommended or required depending upon the option requirements as part of the application for graduate admission. Applicants should refer to the Graduate Office website for additional details.

A test of English proficiency is required for applicants who are non-native English speakers. See below for details.

International Students

In order to be admitted for graduate study, students from non-English-speaking countries are expected to read, write, and speak English and comprehend the spoken language. Although not required for admission, it is important to demonstrate a strong capability in English prior to admission to Caltech. In addition, to be a candidate for an advanced degree, the student must have clear self-expression in both oral and written English.

Applicants whose first or native language is not English or have not received a degree from a university or college where English is the primary language of instruction are required to take a test of English proficiency as part of the application process. Caltech recognizes scores from the Educational Testing Service (TOEFL), Pearson Test of English Academic (PTE Academic), and from the Cambridge Examinations and the International English Language Testing System (IELTS). Applicants should arrange for the results of these tests to be sent to the Graduate Office (institutional code 4034) prior to the relevant application deadline. Testing schedules and information on the TOEFL may be obtained online at www.toefl.org. Testing schedules and information on the IELTS exam may be obtained online at www.ielts.org.

Students who do not achieve a high score on these tests, or who have had little opportunity to communicate in English, are highly recommended to make arrangements for intensive work during the summer preceding their registration. All international students are evaluated upon arrival at Caltech and, if it is determined that additional instruction in English is needed, they will be assigned to an English as a Second Language (ESL) course.

VISITING STUDENT APPOINTMENTS

A limited number of visiting student appointments are made each year. Visiting student status is restricted to students who hold a bachelor's degree and are current graduate students at another institution. The invitation process requires sponsorship by a Caltech faculty member, and requests should be made directly to

the Graduate Office, following the visiting student instructions on the Graduate Office website. The Dean of Graduate Studies may limit the number of visiting students in any given year. Visiting students are subject to the Honor System (see page 20) and other Institute policies and are under the purview of the Dean of Graduate Studies. Visiting students are categorized into two main classifications.

Special Students

Special Students enroll as full-time students (36 units), in a research course and/or coursework numbered 100 or higher, which may be transferred to their home institution. Special Student appointments are allowed for one year, renewable each year up to a maximum of three years. Special Students will not be considered to be working toward a Caltech degree, and courses taken under this program cannot be used to fulfill the requirements for a Caltech degree, nor does registration count toward the minimum residency requirement for an advanced degree.

Special Students are eligible for the same privileges as regularly enrolled graduate students, and will be billed for tuition and fees. Short-term Special Students that do not need academic credit must still enroll in a research class for a minimum number of units and will be billed tuition and fees based on the level of enrollment and the length of stay. For those students who receive a Caltech stipend, tuition remission will be charged to the faculty hosts' supporting grant to cover the tuition and fees assessment. Special Students who do not receive a Caltech stipend will be billed a reduced tuition and fees rate. (For current rates, see the expense summary on page 349.)

Visiting Student Researchers

The Visiting Student Researcher status is limited to short-term visits of one month to one year and is not renewable. Visiting Student Researchers are not eligible to enroll in a research course and/or coursework, and will not receive academic credit from Caltech, but will receive a Caltech identification card. Visiting Student Researchers are also required to provide proof of health insurance and any required medical and immunization records for the duration of the visit.

Students in this status are not eligible to receive a salary through the Institute payroll, and are not eligible for Caltech privileges that are extended to enrolled students. They may be reimbursed for research-related expenses only, but it is the Caltech faculty host's responsibility to ensure that the supporting grant can be used for such purposes and that there are no restrictions on spending. Students receiving a salary through the Institute payroll and/or requiring a transcript to transfer academic credit must be appointed as Special Students.

Exchange Programs

Some academic options have formal exchange programs that they have arranged with other institutions. Exchange students must have a visiting student appointment, and the type of appointment will depend upon the terms of the agreement for the particular exchange program. These programs are administered by the option, and requests should be made directly to the Graduate Office following the same procedure for visiting students.

GRADUATE RESIDENCE

One term of residence shall consist of one term's work of not fewer than 36 units of advanced work in which a passing grade is recorded. Advanced work is defined as study or research in courses whose designated course number is 100 or above. If fewer than 36 units are successfully carried, the residence will be regarded as short by the same ratio, but the completion of a greater number of units in any one term will not be regarded as increasing the residence. In general, the residency requirements are as follows: for Master of Science, a minimum of three terms of enrollment; for the degree of Engineer, a minimum of eight terms of enrollment; and for Doctor of Philosophy, a minimum of 12 terms of enrollment, four of which must be at the Institute.

REGISTRATION

Graduate students are required to register for each term, including summer, whether they are taking classes, conducting research, doing independent reading, writing a thesis, or utilizing any other academic service or campus facility.

A graduate student must be registered for a minimum of 36 research and/or course units to be classified as a full-time student, and may not enroll in excess of 36 research units. A graduate student who registers for less than 36 total units, or who undertakes activities related to the Institute aggregating more than 62 hours per week (in class, research, and teaching assistantship units), must receive approval in advance from the Dean of Graduate Studies. A petition for this purpose may be obtained from the Graduate Office website and must carry the recommendation of the option representative of the student's major option before submission.

Graduate students register during a two-week period each quarter. A late registration fee of \$50 is assessed for failure to register on time. Graduate students with a Bursar's bill balance of \$1,500 or more may have a hold placed on their registration for the subsequent term the day before online registration opens. The hold will be released once students have paid their bill or worked out a satisfactory payment plan with the Bursar's Office.

Before registering, students should consult with their adviser. An adviser is assigned to each entering graduate student by the

option representative. In most options, a new adviser is assigned when the student begins research. Only members of the professorial faculty may serve as advisers. With the approval of the Dean of Graduate Studies, any graduate student whose work is not satisfactory may be refused registration at the beginning of any term by the division in which the student is doing their major work. See the section on Satisfactory Academic Progress for more information.

In registering for research, students should indicate the name of the instructor in charge, and should consult with the instructor to determine the number of units to which the proposed work corresponds. At the end of the term, the instructor in charge may decrease the number of units for which credit is given if the instructor feels that the progress of the research does not justify the original amount.

Students will not receive credit for courses unless they are properly registered. Students themselves are responsible for making certain that all grades to which they are entitled have been properly recorded. Please note that graduate students who enroll in courses numbered below 100 will not receive credit for those courses unless the course(s) is specified in the requirements for a graduate degree as stipulated in the Catalog.

All changes in registration must be reported to the Registrar's Office by the student. Such changes are governed by the last dates for adding or dropping courses as shown on the Academic Calendar on pages 4 and 5. A student may not withdraw from or add a course after the last date for dropping or adding courses without the option's consent, written approval from the instructor of the relevant course, and the approval of the Dean of Graduate Studies.

If the withdrawal occurs after Add Day of any term, a W (standing for "withdrawn") will be recorded on the student's transcript for all courses in which the student is enrolled. A grade of W is not included in the computation of the student's grade-point average.

Academic Year and Summer Registration

Most courses are taught during the three 12-week quarters that make up the academic year. However, doctoral-level students are required to maintain enrollment throughout each term, including the summer. They are entitled to at least two weeks' annual vacation (in addition to Institute holidays), and they should arrange their vacation schedules with their research advisers early in each academic year. Any questions should be referred to the Dean of Graduate Studies.

All students in residence must be registered. There is no tuition charge for summer research units. To maintain full-time student status, a minimum of 36 units must be taken during each term of enrollment.

GRADUATE STUDENT LEAVES OF ABSENCE

General Administrative Requirements

Graduate students are required to have continuity in registration, maintain full-time status, make satisfactory progress, and be in residence until all requirements for a degree are fulfilled. This includes the summer term. This means that students must either be registered, enrolled or on an approved leave from the Institute. Reduced duty status maintains registration for a student who cannot carry a full load due to a medical condition, disability or pregnancy.

Registration is required for the term in which the thesis defense is undertaken, with the exception of the first week of each term. Approval of the Dean is required for any student seeking to enroll for subsequent terms beyond the defense during the academic year. Once the degree is conferred, further enrollment as a graduate student is not permitted.

Detached duty status maintains registration for a student doing research at an external location, such as a national laboratory or another academic institution, for an extended period.

Petitions for Leave

Petition forms for leaves may be obtained from the Graduate Office website and must, before submission to the Dean, carry the acknowledgment of the student's option representative and, where appropriate, the thesis adviser. Petitions for medical leave must carry the recommendation of the Executive Director of Student Wellness Services or their designee. In case of a lapse in status, readmission must be sought before academic work may be resumed or requirements for the degree completed.

While on Leave

A student on a personal, medical or involuntary leave may not attend classes, live in Institute housing, participate in Institute programs, use Institute facilities, work on campus, or use student resources such as Student Wellness Services, Center for Diversity, Career Services or the Center for Teaching, Learning, and Outreach (CTLO) during the leave, unless approved in writing by the Dean.

Voluntary Leaves

Personal Leaves

A student may request a voluntary leave of absence for personal reasons by submitting a personal (non-medical) leave petition to the Graduate Office for approval. International students should consult with the International Student Programs (ISP) office regarding visa implications prior to submitting the leave petition.

The Dean may grant a personal leave provided (a) the student is

making satisfactory academic progress as determined by the student's adviser, (b) the leave is for one year or less, although special circumstances can be considered for a longer leave, and (c) the leave extends over a period that includes at least one full term.

A petition to return from a personal leave should be submitted six (6) weeks before the first day of the term for which the student intends to return. Return from a personal leave is subject to the approval of the Dean and is subject to the student having an approved adviser and ongoing funding to support the student's research. If a student does not anticipate having an adviser upon return, they will need to work with the option representative to arrange for funding and a new adviser in advance of the return. Return will only be granted once an adviser and funding are in place.

Medical Leaves

If a student is unable to complete their coursework or other course of study due to medical reasons, the student may petition for a medical leave of absence by submitting a medical leave petition to the Graduate Office for approval. The petition for medical leave must be recommended by the Executive Director of Student Wellness Services or their 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 health care provider. Students may be required to sign a release of information form authorizing their health care provider to communicate relevant medical information to representatives within Student Wellness Services and the Graduate Office to facilitate evaluation of the need for the leave and to determine appropriate conditions associated with the leave and 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 Student Wellness Services and the Graduate Office, and an independent evaluation of the student's readiness to return by a qualified medical professional. Any conditions of return will be specified at the time of the leave approval.

A petition to return from medical leave must be submitted six (6) weeks before the anticipated term for which the student intends to return. The return process includes an interview with the Executive

Director of Student Wellness Services or their designee and the submission of a completed return from medical leave petition and provider recommendation. Students are expected to sign a release of information form authorizing their treatment providers to communicate with Caltech, including representatives of Student Wellness Services and the Graduate Office to determine readiness to return and any recommendations for reasonable accommodations. Return from a medical leave of absence is subject to the final approval of the Dean.

A student returning from a leave for medical reasons will maintain the same academic standing that they had prior to the leave. Additional information and resources regarding medical leave, including financial and transcript implications, can be found at <https://www.gradoffice.caltech.edu/current/LeavePolicy>.

Pregnancy

Consistent with Caltech policy, the requirements of Title IX, and Section 66281.7 of the California Education Code, students who are unable to complete their coursework or other course of study for a period of time due to a pregnancy, childbirth and related medical conditions are eligible for a pregnancy leave of absence. Students who are pregnant or who have recently given birth are also eligible for reasonable accommodations.

Students are not required to take a leave of absence, withdraw, or limit their graduate studies because of pregnancy, childbirth or related medical conditions. However, students who are disabled due to pregnancy, childbirth and related medical conditions are eligible to take a pregnancy leave of absence. The Institute provides up to six (6) weeks of pay to students during a pregnancy leave of absence; an additional 6 weeks of pay is available through family bonding leave (see following section).

A pregnant student who wishes to take a pregnancy leave should submit a pregnancy leave petition to the Graduate Office. Medical documentation from the student's treating health care provider may be required.

A student who chooses to take a leave of absence because they are pregnant or have recently given birth shall be allowed an additional period commensurate with the length of the leave, but not to exceed 12 additional months, to prepare for and take preliminary and qualifying examinations and an equal extension of time toward the normative time to degree while in candidacy for a graduate degree, unless a longer extension is medically necessary.

An enrolled student in good academic standing who chooses to take a leave of absence because they are pregnant or have recently given birth shall return to their program in good academic standing following an approved leave period of up to one academic year, subject to the administrative requirements described above, unless there is a medical reason for a longer leave, in which case standing

in the graduate program shall be maintained during that period of the leave.

The Institute also provides reasonable accommodations to pregnant students consistent with federal and state law. Reasonable accommodations may include allowing pregnant students to maintain a safe distance from hazardous substances, allowing them to make up tests and assignments that are missed for pregnancy-related reasons or excusing of absences that are medically necessary.

Bonding

Students may take six (6) weeks of family bonding leave with pay. An enrolled student in good academic standing who chooses to take a leave of absence because of the recent birth or adoption of his or her child may request a bonding leave by submitting a bonding leave petition to the Graduate Office for approval. Bonding leave is in addition to pregnancy leave, providing eligible students with a combined total of up to 12 weeks of paid leave. Students returning from an approved bonding leave shall return to his or her program in good academic standing following the leave, subject to the administrative requirements described above.

Involuntary Leave

The Dean or designee may determine that it is necessary to place a student on an involuntary leave in a variety of circumstances, including when a student demonstrates behavior that poses a threat to health or safety, causes significant disruption to the Caltech community, for the personal safety or welfare of the student involved, as an interim measure, or as a result of a disciplinary action. The Dean may impose an involuntary leave in appropriate circumstances, such as where a student's behavior: (1) has, or threatens to, cause significant property damage; (2) significantly disrupts the Caltech community; (3) presents a substantial risk of harm to self or others; (4) indicates the student is unable or unwilling to carry out self-care obligations; or (5) violates a Caltech policy or the honor system. An involuntary leave also may be imposed when the student requires a level of care from the Institute community that exceeds the reasonable accommodations, resources and staffing that the Institute can reasonably be expected to provide for the student's well-being.

Review and Decision Process

If the conduct has been the subject of an investigation or review under an Institute process or procedure, the Dean will consider the findings and conclusions reached in that process. In other circumstances described above, in making an informed decision to place a student on involuntary leave, the Dean will conduct an individualized assessment and consider relevant information including information provided in a timely manner by the student.

The Dean may consult with other Institute personnel, including but not limited to Security and Residential Life personnel, faculty, staff and other individuals or departments. If appropriate and feasible, the Dean may seek cooperation and involvement of parents or guardians of the student.

Medical information, including medical information provided in a timely manner by the student, may be considered if the behavior is associated with a physical or mental condition. In appropriate cases, the Dean may consult with the Executive Director of Student Wellness Services or their 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.

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 consid-

er 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

If a decision by the Dean to place a student on involuntary leave is imposed as a sanction resulting from a finding of responsibility under an Institute process or procedure, appeal rights and limitations, such as limitations on grounds for appeal, are governed by the applicable Institute process or procedure. In all other cases, 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).

GUIDELINES FOR GRADUATE STUDENT ADVISING

The relationship between a faculty adviser and graduate student should be founded on mutual respect and open communication. Advisers and students should discuss the nature of their working relationship early and continue this discussion throughout their period of collaboration to ensure mutually understood and compatible expectations. These discussions should be frequent and open, and should include not only work, research goals, and performance reviews, but also change of status, time for personal and family responsibilities, time off, and concerns about academic or work situations. Both the student and adviser have the obligation to initiate meetings as necessary to ensure the success of the relationship.

After achieving candidacy, each Ph.D. student should be assigned a thesis advising committee consisting of a minimum of three professorial faculty members. This committee typically meets at least once a year beginning after candidacy or the fourth year of graduate study.

The graduate student-faculty adviser relationship should be guided by norms of fairness and professionalism. Both faculty and graduate students should avoid relationships that conflict with their respective roles and duties at Caltech. Both are bound by the prevailing policies prohibiting discrimination and harassment (Nondiscrimination Policy, page 92; Gender-Based Misconduct, page 64, and Unlawful Harassment, page 100). Concerns relating to academic or work situations should be raised promptly between the persons directly involved, and handled informally if possible. Both students and advisers have the responsibility to raise and address concerns and conflicts promptly, honestly, and in a manner that conforms with academic integrity and professionalism. Caltech policy requires that students' concerns be addressed fairly and promptly, and prohibits retaliation or discrimination against students for appropriately voicing or raising a concern.

If a problem remains unresolved or if direct discussion is not

possible, a student can seek assistance from division officers (e.g., option representatives) or the graduate Deans. At any time, a student may request that discussions remain confidential. For more details about sources of assistance, consult the graduate option regulations (starting on page 339) and the Student Problem Resolution Process (page 42).

PART-TIME PROGRAMS

Part-time graduate study programs at the Institute are for Master's seeking graduate students who cannot devote full time to their studies and such students are subject to the following rules:

Degree Programs

- Applicants for the part-time Master's program must submit a regular application form accompanied by a detailed plan for meeting the course requirements for the degree.
- Any research work done for academic credit shall be supervised by a Caltech faculty member.
- In general, students admitted to the part-time program are required to take at least 27 units of graduate course work and/or research each term.
- The part-time program is limited to two years of academic residence.
- Any option at the Institute retains the right to not participate in the program or to accept it under more stringent conditions.

Non-degree Programs

Caltech employees, both campus and JPL, are eligible to apply to take one or more graduate courses for credit. Participants in this program will not be considered to be working toward a Caltech degree, in contrast to the part-time program for graduate degrees described above, and courses taken under this program cannot be used to fulfill the requirements for a Caltech degree.

At least one month prior to the start of the term, the employee should have an initial discussion with the option representative of the option in which the course is to be taken. Application should be made to the Graduate Office by completing the special form provided for this purpose, and providing a transcript of academic work and a letter of recommendation. The employee must meet the prerequisites for the course, and must obtain the written permission of the instructor. The decision on admission to take each course will be made by the course instructor and the option representative, with final approval by the Dean of Graduate Studies. Taking an additional course at a later time will require full reapplication. It is the employee's responsibility to arrange a revised work schedule with the appropriate supervisor and approval of the employee's supervisor is required.

Part-time non-degree students are subject to the Honor System

(see page 20) and are under the purview of the Dean of Graduate Studies. They may take only courses numbered 100 or higher and research courses are excluded from the program. For courses in which a letter grade is offered, these students may not register to receive a pass/fail grade in the course, nor can credit for the course be obtained by examination. The option may limit the number of non-degree students admitted to any one course.

RESPONSIBLE CONDUCT OF RESEARCH

Caltech researchers are expected to adhere to the highest professional standards in the conduct of research. Faculty members are charged by the Institute with the responsibility to safeguard the basic principles of research integrity, academic freedom, and public interest. Students are expected to also follow these same principles. When government funds are involved in the support of research, investigators are required to take specific steps to adhere to all rules and regulations of the government and sponsoring agencies. Students are required to have specific training in research ethics and integrity as well as conform to standards established by research supervisors or their laboratories. There are two situations in which this is mandated by federal law.

National Institutes of Health

Students that are funded through NIH grants, work with human or vertebrate animal subjects, or are required as part of their academic option's curriculum, have to meet a NIH requirement for training in specified areas as described in the Caltech Guide to Sponsored Research. In order to meet the NIH requirement, Caltech requires that all trainees supported by NIH funds take Biology course 252 "Responsible Conduct of Research."

National Science Foundation

Training in Responsible Conduct of Research is also required of students funded on NSF awards, including the GRFP program. In order to satisfy the NSF mandate, Caltech requires that students supported from NSF funds as described above shall take the online course on Research Ethics Education (CITI).

If a student can document having passed a similar, qualifying program at another institution, Caltech may accept that in lieu of completing Caltech's program. You must submit documentation in the form of a transcript or certificate to the Graduate Office to receive credit for previous work. A passing grade in Bi 252 is an acceptable alternative to passing the CITI online Responsible Conduct of Research course.

CONFLICT OF INTEREST AND COMMITMENT OF GRADUATE STUDENTS

The Institute has a long-standing philosophy that all graduate students should be given the opportunity to be completely focused on graduate studies and research. This is one of the unique aspects of Caltech's graduate school and a key factor in the high level of productivity and accomplishment by our graduate students. To enable this, the faculty and Institute provide financial aid in the form of fellowships, tuition scholarships, graduate teaching, and research assistantships. The stipend and salary levels for students are modest but sufficient for economical students to live debt-free during their graduate studies. The financial support provided by the Institute and the requirements for continuous enrollment also enable almost all students to complete the degree programs in a timely manner.

In turn, the Institute expects that graduate students should be 100 percent committed to graduate studies while enrolled in a graduate program. Graduate students are expected to be continuously enrolled full-time, year-round, until they complete their degree program. In addition, graduate students should not accept employment, start or run a business, or engage in any activity inside or outside of the Institute that creates a conflict of commitment with their full-time, degree-seeking status.

Exceptions

There are some very limited exceptions to this policy. The Institute encourages extracurricular activities that provide service to the community and do not impact the student's academic progress or full-time status. The Institute also recognizes that some students desire to gain experience as instructors or work in an educational or research setting outside of Caltech.

Outside Employment

With the permission of the Dean of Graduate Studies, students may accept limited-duration, part-time employment for these purposes (see Financial Assistance, page 350). Students must declare to the Dean of Graduate Studies all external funding, including fellowships, awards, or employment, part- or full-time, which supports their academic activities/research. The Institute may adjust Institute financial aid allocated accordingly to maintain the stipend within the Institute guidelines and to recover tuition from outside sources whenever possible. A student's financial aid and/or Institute salary may be reduced if the income is significant, and in the case of long-term, unreported employment activities, the student may be asked to repay financial aid.

Students may not hold a position of line responsibility in an outside enterprise for pay or profit. Students must have the approval of their adviser, the option representative, and the Dean

of Graduate Studies in order to engage in any outside employment activities.

International students on a visa are further required to consult with the office of International Student Programs to determine eligibility. Students must provide official documentation of the financial award or salary, as well as submit a request to the Graduate Office before accepting any employment. Permission to engage in outside employment is contingent on the student maintaining satisfactory academic progress as determined by the Dean of Graduate Studies in consultation with the adviser and option representative.

Non-Paid Activities

Students must have the approval of their adviser, the option representative, and the Dean of Graduate Studies in order to engage in or continue in any outside activities wherein the time committed to those activities may impact the student's progress toward completion of degree requirements.

Leave of Absence

Students who work full-time off campus in a commercial organization are advised to take a leave of absence (non-medical sabbatical). They will not be enrolled during this time, and the "clock" will stop on their graduate career. Taking a leave of absence in order to work requires the endorsement of the adviser and permission of the Dean of Graduate Studies. A leave of absence is always required when the job is not research-related. Students who need to stop their studies to address health issues should take a medical leave of absence, which requires the endorsement of Student Wellness Services as well as the permission of the Dean of Graduate Studies.

Detached Duty

In some cases, a student may be engaged in research at an external laboratory or research institute under the supervision of a Caltech faculty adviser, and conducting research that is directly related to their degree program. Another situation is that a student may be invited to be a visiting researcher at another university, or the student may need to be working with a faculty member who has left Caltech and is working at another institution.

Students may go on detached duty rather than on leave of absence if the adviser and Dean of Graduate Studies approve and there is documentation of a research program integral to their thesis project and appropriate mentoring. Students on detached duty should have completed their residency requirements and advanced to candidacy prior to moving to the host institution.

The student should submit the documentation and a petition form to the Graduate Office. Students on detached duty are still enrolled as full-time students but are in residence at another loca-

tion. They may be paid by Caltech or through another organization. It is the student's responsibility to continue to be in good standing, and registered and in full-time status while on detached duty. Detached duty petitions are usually valid for a limited time, less than one year, and may be renewed upon request.

Consulting and Other Entrepreneurial Activities

Graduate students are sometimes approached to perform paid consulting or are inspired to be entrepreneurs. In these cases, students have to be exceptionally careful not to create conflicts of commitment or conflicts of interest through these activities. Students considering these activities should familiarize themselves with the Caltech policies on conflict of interest, outside employment or business activity, and the Caltech ethics handbook. Students may not engage in any consulting activities that interfere with their primary graduate student activities of learning and research. Scrupulous care must be taken to ensure that Caltech's name and its letterhead are used neither directly in any correspondence between the student and the company the student wishes to consult for, nor in any reports that student may submit to the company.

Of particular concern are students consulting or accepting employment from a company in which their adviser or other Caltech faculty member is directing a student's research and has a significant interest or is a paid consultant. In such cases, the Division Chair must approve any student involvement in the activities performed for the company. The student must submit a written disclosure, and a conflict management plan will be put in place.

Graduate students should not enter into any consulting or employment agreement with intellectual property encumbrances or confidentiality provisions that are in conflict with the student's commitments to Caltech or that may compromise academic progress.

Please refer to the Graduate Office website for the complete policy and regulations regarding conflicts of commitment and interest. If there are any questions about the propriety of any outside activity or agreements, this should be discussed with the Graduate Office and, if necessary, the Office of Research Compliance and the Office of the General Counsel.

WORKING AT SPECIAL LABORATORIES

Students who desire to take advantage of the unique opportunities available at one of the special laboratories (e.g., JPL) for Ph.D. thesis work may be allowed to do so provided that they maintain good contact with academic life on campus, the laboratory involved commits financial support for the duration of the thesis research, and all Caltech graduate thesis research carried out at a special laboratory is under the supervision of Caltech faculty members.

A student's request to carry out thesis work at a special laboratory should be formally endorsed by the appropriate committee of

his or her option and by the special laboratory, on a petition submitted through the option representative to the Dean of Graduate Studies. The special laboratory should recognize its commitment of special equipment or any other resources required for the thesis work. Approval by the special laboratory should also indicate that the thesis topic is a sensible one, and that it is not likely to be preempted by the laboratory.

A student may take similar advantage of unique opportunities at a corporate or governmental research and development facility under the same conditions, providing that there exists a formal written agreement between the R&D facility and the student's thesis adviser, and that advance written approval is obtained from the Dean of Graduate Studies. Such training may in some cases involve full-time employment at the laboratory for a limited period of time for the purpose of engaging in the essential data collection that is integral to a student's thesis. Typically, such students who are not in a local laboratory are placed on detached duty status.

Employment by a special laboratory of a graduate student for work not connected with the thesis should be regarded as equivalent to other outside employment.

EXCHANGE PROGRAM WITH SCRIPPS INSTITUTION OF OCEANOGRAPHY

An exchange program with the Scripps Institution of Oceanography (SIO), University of California, San Diego, permits Caltech graduate students to enroll in and receive credit for graduate courses offered by SIO. Arrangements should be made through the student's major option and the Graduate Office. The student must obtain the advance approval of the instructors of courses to be taken at SIO. In some cases, arrangements may be made for the student to be temporarily in full-time residence at SIO.

Thesis research done partly at SIO may be arranged directly by the student's option and the staff of the appropriate research laboratories at SIO, without the necessity of enrolling for SIO courses designated for research; in this case the student will continue to be under the supervision of the Caltech thesis adviser and will enroll for Caltech research units.

GENERAL REQUIREMENTS FOR GRADUATE DEGREES

DEGREE OF MASTER OF SCIENCE

The Master of Science degree is a professional degree designed to prepare a student for teaching, for further graduate studies, or for more advanced work in industry. Detailed requirements are based primarily on professional studies, and the program should

be planned in consultation with the faculty in the appropriate discipline. Under normal circumstances, the requirements for the Master's degree can be completed in one academic year. Students must declare candidacy for the Master's degree no later than the academic year in which the final degree requirements have been met or upon separation from the Institute. Students who are pursuing a doctoral degree and obtain a Master's along the way, must declare candidacy for the Master's no later than two weeks prior to conferral of the Ph.D.

A student who enters the Institute holding a Master's degree from another institution will not normally be awarded a second Master's degree in the same field. A student will not be awarded two Master's degrees from the Institute.

Special regulations for the Master's degree are listed under each graduate option. Several options do not offer a Master's degree except in special circumstances.

Residence and Units of Graduate Work Required

At least one academic year of residence at the Institute and a minimum of 135 units of graduate work at the Institute subsequent to the baccalaureate degree are required for the Master's degree. Included in these units are at least 27 units of free electives or of required studies in the humanities numbered 100 or above. Advanced courses taken while enrolled as a Caltech undergraduate student in excess of the bachelor's degree requirements may be counted toward the Master's degree requirements with the approval of the academic option representative and the Dean of Graduate Studies.

To qualify for a Master's degree, a student must complete the work indicated in the section on special regulations for their option with a grade-point average for the approved Master's candidacy courses of at least 1.9.

In special cases, with the approval of the instructor, option representative, and the Dean of Graduate Studies, courses taken elsewhere before enrollment at the Institute may be offered in place of specifically required courses. An examination may be required to determine the acceptability of such courses. Course credit, if granted, shall not count toward the 135-unit and residency requirements.

Admission to M.S. Candidacy

By the third term of the academic year in which the student expects to receive the degree, candidates should have completed a plan of study in Regis, which must have the approval of the option representative and, in some cases, of the research adviser. This approved plan of study will constitute requirements for the degree. Any modifications to the plan of study must be approved by the option representative no later than two weeks before the degree is to be conferred. Some options require a thesis or

research report in addition to course requirements. The thesis or research report must be approved by the research adviser and option representative no later than two weeks before the degree is to be conferred. For additional information and option-specific requirements, please refer to the section “Special Regulations for Graduate Options.”

Joint B.S./M.S. Degree

In exceptional cases, undergraduate students may be eligible to pursue a joint B.S./M.S. program of study to be completed within the four years (12 terms) of the undergraduate program. Students should contact the graduate option representative to find out if the joint B.S./M.S. degree is offered in a particular option. If so, students must follow the normal procedures for admission to the graduate program. Students admitted to the joint B.S./M.S. degree must complete a minimum of 486 units for the B.S. program and an additional 135 units for the M.S. program with no overlapping of courses. In addition, a written plan of study must be submitted to the Registrar’s Office for approval no later than the fall term of the senior year. The plan of study should provide detail of the courses that are proposed to satisfy each degree requirement within the twelve terms of the B.S. program and once approved shall constitute the requirements for the degree. Any changes to the plan require written approval by the Registrar. If not completed within the four years, students will be removed from the joint program and they, and all their courses, will be attached to the B.S. program. Students enrolled in the joint B.S./M.S. degree will be considered undergraduate students and will not be eligible for graduate financial aid, graduate housing, or other graduate student privileges.

ENGINEER’S DEGREE

Engineer’s degrees are awarded in exceptional circumstances. The work for an Engineer’s degree must consist of advanced studies and research in the field appropriate to the degree desired. It must conform to the special requirements established for that degree and should be planned in consultation with the members of the faculty concerned. Students who have been admitted to the terminal Master’s degree and wish to pursue further studies leading toward either the Engineer’s or the Ph.D. degree must file a petition (and in some cases must file a new application) to continue graduate work toward the desired degree. Students who have received an Engineer’s degree will not be admitted for the Ph.D.

Residence

At least eight terms of graduate residence subsequent to a Bachelor’s degree equivalent to that given by the Institute are required for an Engineer’s degree. Of these, at least three terms

must be at Caltech. It must be understood that these are minimum requirements, and students must often count on spending a somewhat longer time on graduate work.

To qualify for an Engineer's degree, a student must complete the work prescribed by the supervising committee with a grade-point average of at least 1.9. Research work and the preparation of a thesis must constitute no fewer than 55 units. More than 55 units may be required by certain options, and the student should determine the particular requirements of their option when establishing a program.

Admission to Candidacy

Before the midpoint of the first term of the academic year in which the student expects to receive the degree, he or she must complete a proposed plan of study and, in consultation with the chair of the appropriate division, will select a committee comprised of at least three members of the professorial faculty to supervise the student's work and to certify its satisfactory completion. The student should consult with this committee in planning the details of their work. The plan of study shall then constitute the requirements for the degree. Any modifications must be approved by the option representative at least two weeks before the degree is conferred.

The student will be admitted to candidacy for the degree when the supervising committee certifies (a) that all the special requirements for the desired degree have been met, with the exception that certain courses of not more than two terms in length may be taken after admission to candidacy; (b) that the thesis research has been satisfactorily started and can be finished at the expected date; (c) that the candidate demonstrates competence in oral and written English.

Admission to candidacy should be obtained by the midpoint of the term in which the degree is to be granted, but no later than the academic year in which the final degree requirements have been met or upon separation from the Institute.

Thesis

At least two weeks before the degree is to be conferred, each student is required to submit a thesis in accordance with the regulations that govern the preparation of doctoral dissertations. These regulations may be obtained from the Graduate Office website.

The use of "classified" research as thesis material for any degree will not be permitted. Exceptions to this rule can be made only under special circumstances, and then only when approval is given by the Dean of Graduate Studies before the research is undertaken.

Examination

At the discretion of the option in which the degree is desired, a final examination may be required. This examination would be con-

ducted by a committee appointed by the candidate's supervising committee.

DEGREE OF DOCTOR OF PHILOSOPHY

The degree of Doctor of Philosophy (Ph.D.) is conferred by the Institute primarily in recognition of breadth of scholarship, depth of research, and the power to investigate problems independently and efficiently, rather than for the completion of definite courses of study through a stated period of residence. The work for the degree must consist of research and the preparation of a thesis describing it, and of systematic studies of an advanced character, primarily in science or engineering. In addition, the candidate must have clear self-expression in both oral and written English.

Subject to the general supervision of the Committee on Graduate Study, the student's work for the Ph.D. degree is specifically directed by the division in which he or she has chosen the major subject. Each student should consult with their division concerning special divisional and option requirements.

Admission

With the approval of the Dean of Graduate Studies, students are admitted to graduate standing by the option in which they choose their major work toward the Ph.D. degree. In some cases, applicants for the Ph.D. may be required to complete requirements for the M.S. degree first; however, this is not a general prerequisite for the Ph.D. Students who have received an Engineer's degree will not be admitted for the Ph.D. degree.

A student who holds a Ph.D. or the equivalent from another institution will not normally be admitted to graduate standing at Caltech to pursue a second Ph.D. degree. A student will not normally be awarded two Ph.D. degrees from the Institute.

Minor Programs of Study

The Institute does not require a minor for the Ph.D. degree, but the individual options may have minor requirements as part of their requirements for the major.

A student may undertake a minor program of study in most options as specified in this catalog under the section "Special Regulations of Graduate Options." Completion of a minor program of study is recognized on the diploma by the statement "...and by additional studies constituting a minor in [name of option]."

A minor program of study should be at a level of study in the minor substantially beyond that typically acquired by students as part of their major requirements. Most options require 45 units or more, including at least one 200-level course and a coherent program of the supporting 100-level courses. The faculty of the minor option may approve a proposed minor program on the basis of overall class performance and/or by an oral examination.

Detailed requirements for minor options are listed under the individual options. Students cannot use courses required by their major option in fulfillment of the minor requirement.

Residence

At least three academic years (12 terms) of residence subsequent to a baccalaureate degree equivalent to that given by the Institute are required for the Ph.D. Of this, at least one year (4 terms) must be in residence at the Institute. It should be understood that these are minimum requirements, and students must usually count on spending a somewhat longer time in residence. A student whose undergraduate work has been insufficient in amount or too narrowly specialized, or whose preparation in their special field is inadequate, should plan upon spending increased time in work for the degree.

However, no student will be allowed to continue work toward the Ph.D. degree for more than six academic years (24 terms) of graduate residence, without a petition approved by the Dean of Graduate Studies. This petition must include a plan and schedule for completion, agreed upon and signed by the student, the thesis adviser, and the option representative.

Registration

Continuity of registration must be maintained until all requirements for the Ph.D. have been completed, with the exception of authorized leaves. Registration is typically required for the term in which the thesis defense is undertaken.

Thesis Advisers and Committee Chairs

The thesis adviser must be a professorial faculty member, defined as professor, associate professor, or assistant professor on a full-time, tenure-track appointment at Caltech. Research faculty and emeritus faculty can supervise research, but the official thesis adviser must be a member of the professorial faculty. Expectations for the relationship between graduate students and faculty advisers are discussed under Guidelines for Graduate Student Advising (page 333).

Progress through the graduate program is monitored in part by the candidacy, thesis advisory, and thesis examination committees detailed in the following sections. Each committee has a chair who is responsible for running the meeting, summarizing the outcome, and working with the graduate student and adviser as appropriate. The chair of each committee is a professorial faculty member distinct from the adviser.

Admission to Candidacy

On the recommendation of the option concerned, the Dean of Graduate Studies will admit a student to candidacy for the degree of Doctor of Philosophy after the student has been admitted to work

toward the Ph.D. and has been in residence at least one term; has initiated a program of study approved by the major option and, if needed, by the minor option; has demonstrated, by written or oral examination, a comprehensive grasp of the major and minor subjects and of subjects fundamental to them; has displayed the ability for clear self-expression in both oral and written English; and has shown ability in carrying on research in a subject approved by the option concerned. Option regulations concerning admission to candidacy are given in a later section.

Depending upon option regulations, candidates will either be assigned a candidacy committee by the option representative or must independently select appropriate members to serve on the candidacy committee. A candidacy committee consists of a minimum of three members, two of whom must be professorial faculty. Emeritus faculty, research faculty, JPL staff and external scholars may serve on the candidacy committee, with approval of the option representative and the Dean of Graduate Studies in advance of the candidacy examination. The student should ensure that all members of the committee are available during the examination period and that they are willing to provide timely and appropriate feedback.

A student not admitted to candidacy by the end of the third year or twelfth term of graduate residence at the Institute must petition the Dean of Graduate Studies for permission to register for further work.

Candidacy (and permission to register) may be withdrawn by formal action of the option from a student whose research is not satisfactory, or for other compelling reasons. However, the option must petition through its division chair to the Dean of Graduate Studies before taking such action.

Thesis Advisory Committee

Each Ph.D. student is assigned a Thesis Advisory Committee consisting of a minimum of three professorial faculty members. Emeritus faculty, research faculty, JPL staff and external scholars may serve on the thesis examination committee with approval of the option representative and the Dean of Graduate Studies. This committee will meet annually following candidacy, or by the fourth year of graduate study.

Thesis Examination

Each Ph.D. candidate shall undergo broad oral examination on the major subject, the scope of the thesis, and its significance in relation to the major subject. The thesis examination, subject to the approval of the Dean of Graduate Studies, may be taken after admission to candidacy whenever the candidate is prepared; however, it must take place at least three weeks before the degree is to be conferred.

The thesis examination may be written in part, and may be subdivided into parts or given all at one time at the discretion of the options concerned. The student must declare their intent to defend by completing the examination notification in Regis not less than two weeks

before the date of the examination. A thesis examination committee consists of four members, with a minimum of three professorial faculty. Emeritus faculty, research faculty, JPL staff and external scholars may serve on the thesis examination committee with approval of the option representative and the Dean of Graduate Studies in advance of the thesis examination.

Thesis

At least two weeks before the final oral examination, the candidate should provide a draft copy of a completed thesis to the Graduate Office for proofreading and to the members of the thesis examination committee. The date of the examination and the composition of the thesis examination committee should be posted in Regis at least two weeks before the final defense is scheduled. In general, registration is required for the term in which the thesis defense is undertaken. Approval of the Dean of Graduate Studies is required for any student seeking to enroll for subsequent terms following the thesis defense. A student not receiving Caltech funding, may petition the Dean of Graduate Studies for a tuition waiver if the student schedules the examination by the third Friday of the term in which the examination will be taken.

The last date to upload the final, corrected thesis is the fifth week of the succeeding term if the candidate defended their thesis during the previous summer or the fall or winter terms; or two weeks before the degree is to be conferred if the candidate defended their thesis during the month of May. It is required that all Ph.D. candidates submit an electronic copy of their dissertation, which the Caltech Library System will then archive and make available online as part of the Networked Digital Library of Theses and Dissertations (NDLTD), an international organization that allows researchers to globally search a database of electronic theses and dissertations. For special option regulations concerning theses or the exam composition, see specific graduate options.

Before uploading the final, corrected thesis, it is the candidate's responsibility to obtain approval of the thesis by the option representative and all members of the thesis examination committee.

With the approval of the option concerned, a portion of the thesis may consist of one or more articles published jointly by the candidate and members of the Institute staff or other coauthors. In any case, however, a substantial portion of the thesis must be the candidate's own exposition of their own work.

The use of "classified" research as thesis material for any degree is not permitted. Exceptions to this rule can be made only under special circumstances, and then only when approval is given by the Dean of Graduate Studies before the research is undertaken.

Regulations and directions for the preparation of theses may be obtained from the Graduate Office website, and should be followed carefully by the candidate. Thesis templates are also available on the Library website.

SATISFACTORY ACADEMIC PROGRESS

In order to continue in a degree program and to receive financial aid at Caltech, graduate students must maintain satisfactory academic progress toward completion of their degree. Continuity of registration must be maintained until all requirements for the degree being sought have been completed, with the exception of authorized sabbaticals.

The Master of Science degree requires at least three terms of residence at the Institute and a minimum of 135 units of graduate work with a grade-point average of at least 1.9. A Master's degree cannot take more than two years without a petition approved by the Dean of Graduate Studies.

The Engineer's degree must consist of advanced studies and research in the field appropriate to the degree desired. At least eight terms of graduate residence are required with a minimum 1.9 overall grade-point average. The Engineer's degree cannot take more than twelve terms to complete without a petition approved by the Dean of Graduate Studies.

For the Doctor of Philosophy, at least twelve terms of residence are required, but the necessary study and research typically can be completed in six years or less. The work for the degree consists of research and the preparation of a thesis describing it, and of systematic studies of an advanced character, primarily in science or engineering.

The requirements for each degree include special regulations established by each option and detailed in the Institute Catalog for the year of initial registration. Many options require a C grade or better in particular courses or groups of courses. Hence, a limited number of courses may be repeated while still maintaining a status of satisfactory academic progress and would count toward the 36-unit-per-term requirement. A full-time graduate student must register for (and complete) 36 units per term, including the summer term. Approval of the Dean of Graduate Studies is required before dropping any course that brings a student below 36 units. The treatment of incomplete grades and withdrawals is specified on pages 30–35. Satisfactory academic progress is checked each academic term by the Graduate Office.

The special regulations for the options typically include the completion of specific courses, oral and/or written examinations, petitions, research requirements, etc., by specific times. Satisfactory academic progress is judged by the options against these regulations, and revocation of permission to register may be recommended by the option to the Dean of Graduate Studies prior to or in response to the student's petition for admission to candidacy. Further, even after admission to candidacy, the candidacy (and permission to register) may be withdrawn by formal action of an option for a student whose research is not satisfactory, or for other compelling reasons. However, the option must petition through its division chair to the Dean of Graduate

Studies before taking such action. A decision to revoke or withdraw permission to register may be appealed in writing within ten days to the Vice President for Student Affairs or designee.

A Ph.D. student who has not been admitted to candidacy by the beginning of the fourth year (12 terms) must petition the Dean of Graduate Studies for permission to register for further work. In addition, no Ph.D. student will be allowed to register for more than 24 terms without a petition approved by the Dean of Graduate Studies.

This petition must include a plan and schedule for completion, agreed upon and signed by the student, the Thesis Advisory Committee chair, and the option representative.

GRADUATE EXPENSES

The tuition and fees charge for all students registering for graduate work is currently \$54,537.00 per academic year, payable at the beginning of each term, fall (10/1/2019), winter (1/6/2020), and spring (3/30/2020). Graduate students who cannot devote full time to their studies are allowed to register only under special circumstances. Students desiring permission to register for fewer than 36 units must therefore petition the Dean of Graduate Studies for an underload.

The payment of tuition by graduate students is required (a) without reference to the character of the work by the student, which may consist of research, independent reading, or writing a thesis or other dissertation, as well as attendance at regular classes; (b) without reference to the number of terms in which the student has already been in residence; and (c) without reference to the status of the student as an appointee of the Institute, except that members of the academic staff of rank of instructor or higher are not required to pay tuition.

Unpaid Bills

All bills owed the Institute must be paid when due. Any student whose bills are past due may be refused registration for the following term. All graduate students with an outstanding bursar's bill balance of \$1,500.00 or more will have a hold placed on their registration for the subsequent term the day before online registration opens. Official transcripts and diplomas will not be released until the bursar's account is paid in full.

Caltech ID Card Charges

If a graduate student owes more than \$1,500.00, the student's charging privileges will be suspended. Charging privileges will be reactivated once students have paid their bill in full with the Bursar's Office.

EXPENSE SUMMARY 2019-2020

General:

Tuition and fees	\$54,537.00
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Other:

General Deposit	\$100
Books and supplies (approx.)	\$1,400.00
Contact Bursar's Office for audit fee.	

Room Catalina apartments:

4 bedroom apt. \$655.00 per person per month (plus utilities)

2 bedroom apt. \$775.00 per person per month (plus utilities)

1 bedroom apt. \$1,315.00 per apt. per month (plus utilities)

Fees are subject to change at the discretion of the Institute.

Fees for Late Payment

A \$50.00 late fee penalty may be charged by the Bursar's Office for failure to clear a past-due account at the beginning of instruction.

Fees for Late Registration

Registration is not complete until the student has registered for a program approved by their adviser and has paid tuition and other fees. A penalty fee of \$50 is assessed for failure to register within five days of the scheduled dates.

Honor System Matters

Monies owed to the Institute resulting from a disciplinary matter may be collected through the Bursar's Office, at the request of the Dean of Graduate Studies.

Housing Facilities

The Catalina Central complex provides approximately 152 single rooms in four-bedroom furnished units. Another, Catalina North, has 156 single rooms in two-bedroom furnished units, and Catalina South has 78 single rooms in two-bedroom furnished units, and 29 one-bedroom furnished units. These apartments are also available to married or coupled students.

Rates for housing vary, depending upon the accommodations and services provided. A contract is required to live in these houses for the academic year. Complete information can be obtained at www.housing.caltech.edu.

There is one Residential Life Coordinator (RLC) and four Resident Associates (RAs) in the Catalina Complex. An RLC is a specially trained full-time university employee, specializing in college student development, community building, counseling, and crisis intervention. The RLC supervises the RAs on programming and overall student wellness. The RLC also assists Housing with the management and daily operations of the complex. There are also Catalina Community Associates (student volunteers) who work with the RLC and RAs on programming and community building in the Catalinas.

The Institute also owns a limited number of apartments and single-family houses that are available for rental, on a lease basis, to single or married/partnered graduate students or graduate students with families. Because of limited availability, there is a waiting list for these properties. For additional information and application, go to www.housing.caltech.edu.

Students preferring to live in non-Institute housing typically pay approximately \$1,000 to \$1,300 per month/each, in rent for a shared apartment, and somewhat more for a private apartment. Please note that the Institute cannot make negotiations for individual housing off campus.

Dining Facilities

Graduate students are granted the privilege of joining the Athenaeum (faculty club), which affords the possibility of contact with fellow graduate students and with others using the Athenaeum, including the Associates of Caltech, distinguished visitors, and members of the professional staffs of the Huntington Library and the California Institute of Technology.

The Chandler Dining Hall, located on the campus, is open Monday through Friday. Breakfast, lunch, and snacks are served cafeteria style. Café at Broad is open for lunch, Monday through Friday.

Health Services

Health services available to graduate students are explained in section one of this Catalog.

FINANCIAL ASSISTANCE

Caltech offers in each of its options a number of fellowships, tuition scholarships, and graduate assistantships. In general, tuition scholarships may be for full or partial tuition charges; assistantships provide stipends; and fellowships often provide both tuition scholarship awards and stipends. Graduate assistants are eligible for tuition awards. Appointments to fellowships, scholarships, and assistantships are decided yearly by the student's academic option.

Graduate students receiving any form of financial award from

the Institute are required to report to the Dean of Graduate Studies any financial aid from other sources. With prior written approval from the Dean of Graduate Studies, students may be allowed to accept outside employment if the time commitment does not interfere with their graduate studies. The number of hours per week spent on outside employment must be reported to the Dean of Graduate Studies.

GRADUATE ASSISTANTSHIPS

Graduate assistants help with teaching, laboratory work, or perform research of a character that affords useful academic experience while permitting a full academic schedule of courses. The specific research and teaching obligations of graduate assistants are agreed upon with the adviser.

Caltech graduate students often receive a combination of teaching and research assistantships; however, the total work commitment cannot exceed 20 hours per week during the academic year. Summer appointments can be greater, with assignments up to 40 hours per week. A graduate student who undertakes activities related to the Institute aggregating more than 62 hours per week (in class, research assistantship, and teaching assistantship hours) must petition the Dean of Graduate Studies.

Graduate assistant stipends are based on four quarters paid monthly throughout the year. Students are also entitled to two weeks of annual vacation and Institute holidays. Students should prearrange their vacation schedule with their adviser. When necessary, graduate assistants may arrange for medical leave, pregnancy leave, bonding leave, or personal leave. Any questions should be referred to the Dean of Graduate Studies.

Teaching Assistantships

A full teaching assistantship usually requires 20 hours per week to be devoted to teaching and to the related activities of class preparation, grading, and consulting with students. In general, teaching obligations are confined to the 12 weeks of the academic terms, excluding summer. A student may not be a teaching assistant for a course in which he or she is enrolled. Only teaching assistants with good oral English and who have fulfilled the Institute English proficiency requirement are permitted to teach sections.

All teaching assistants, including undergraduate students with teaching responsibilities, are required to attend teaching-assistant training before payment can be processed. Training sessions are conducted by the Center for Teaching, Learning, and Outreach (CTLO) and occur in the first week of the fall term, typically during orientation, and at least once per term.

Teaching assistants must familiarize themselves with Caltech's policy on harassment (see pages 100–105) and follow other policies related to teaching discussed in the required training. Classes

should foster academic achievement in a “hassle-free” environment. Teaching assistants should not attempt to date a student in their class, and should disqualify themselves from teaching a section in which a spouse or current partner is enrolled.

Research Assistantships

Research assistantships typically are 20 hours per week during the academic year, but can be as much as 40 hours per week during the summer. The specific duties are decided upon by the adviser.

Graduate Scholarships, Fellowships, and Research Funds

The Institute awards endowed fellowships and scholarships for tuition and/or stipends to graduate students of exceptional ability. Students are also strongly encouraged to apply for scholarships and fellowships from federal and private agencies and organizations to support their graduate studies.

Loans

Several types of loans are available to graduate students. To qualify for any of these, a student must demonstrate financial need and must maintain satisfactory academic progress in the course of study for which he or she is enrolled. Application forms and further information are available from the Financial Aid Office.

Refund and Repayment Policy

Caltech has established an equitable refund policy for students who find it necessary to withdraw or take a sabbatical from the Institute.

Students who officially withdraw or take a sabbatical from the Institute during an academic term may receive a tuition refund (see pages 200–212). Students living in Caltech housing may also be eligible for a partial refund from the Housing Office.

When granting refunds to financial aid recipients or graduate assistants, it is Caltech’s policy to return the refund, in most cases, to the original account.

PRIZES

Amori Doctoral Prize in CMS

Established in 2017 by Michael Amori (MS ’07), this award honors outstanding dissertations in the computing and mathematical sciences during the current academic year. Awardees are selected by a committee of computing and mathematical sciences faculty each spring.

Tom Apostol Award for Excellence in Teaching in Mathematics

For over fifty years, Tom Apostol has represented great math teach-

ing at Caltech. In 2010 the mathematics option at Caltech set up the Apostol Teaching Awards to recognize excellence in teaching by graduate teachers.

Charles D. Babcock Award

The Charles D. Babcock Award recognizes a student whose achievements in teaching (or other ways of assisting students) have made a significant contribution to the aeronautics department. The criteria for the award selection are as follows: The award can be made as unscheduled support for a graduate student associated with aeronautics, e.g., for travel to a technical meeting for professional advancement. All aeronautics-associated students are eligible, with preference given to those in the structures and solid mechanics group. The award may be made yearly, as merited. The timing of the award will be as special recognition warrants. The Charles D. Babcock Award was established in 1992 in memory of Charles D. Babcock, who was professor of aeronautics and applied mechanics until 1987; he served aeronautics as option representative and the Institute as vice provost.

The Bhansali Family Prize in Computer Science

Established in 2001 by Vineer Bhansali (B.S. '87, M.S. '87) in memory of his grandfather, Mag Raj Bhansali, this award is given to an undergraduate student for outstanding research in computer science in the current academic year. Awardees are selected by a committee of computer science faculty.

Bhansali Family Dissertation Prize in Computer Science

Established in 2018 by Vineer Bhansali (B.S. '87, M.S. '87) in memory of his grandfather, Mag Raj Bhansali. This prize and honorarium are given to honor outstanding dissertations in computer science, broadly defined, during the current academic year. Awardees are selected by a committee of computer science faculty each spring.

William F. Ballhaus Prize

A prize will be awarded for an outstanding doctoral dissertation in aeronautics, to be selected by the aeronautics faculty. This award is made possible by a gift from Dr. William F. Ballhaus, a California Institute of Technology alumnus who received his Ph.D. in aeronautics in 1947.

Bohnenblust Travel Grants in Mathematics

Special grants may be awarded to outstanding graduate students in mathematics to enable them to travel in the United States or abroad to further their mathematical education. The mathematics faculty established these awards in 1978 to honor H. F. Bohnenblust, who served Caltech as professor of mathematics, executive officer for mathematics, and Dean of Graduate Studies.

Rolf D. Buhler Memorial Award in Aeronautics

An award is made annually to a student in the aeronautics master's program whose academic performance was exemplary and who shows high potential for future achievements at Caltech. The Rolf D. Buhler Memorial Award in Aeronautics was established in 1990 in memory of Rolf Buhler, a 1952 graduate of GALCIT and professor of space flight at the Technical University of Stuttgart in Germany.

Caltech Alumni Association 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.

W. P. Carey & Co., Inc., Prizes in Applied Mathematics

Prizes will be awarded by a faculty committee in applied mathematics for outstanding doctoral dissertations. If there is no appropriate candidate, then the awardee can be chosen from pure math. These awards have been made possible by gifts from William Polk Carey and from W. P. Carey & Co., Inc.

Centennial Prize for the Best Thesis in Mechanical and Civil Engineering

Awarded each year to a candidate for the degree of Doctor of Philosophy in applied mechanics, civil engineering, or mechanical engineering whose doctoral thesis is judged to be the most original and significant by a faculty committee appointed annually by the executive officer for mechanical and civil engineering. The prize consists of a citation and a cash award and was established with gifts from alumni following the Mechanical Engineering Centennial Celebration in 2007.

Richard Bruce Chapman Memorial Award

A prize will be awarded annually to a graduate student who has distinguished himself or herself in research in the field of fluid dynamics. Bruce Chapman was awarded an M.S. from Caltech in 1966 and a Ph.D. in 1970, both in engineering science. This award has been established in his memory by his family and friends.

Ben P.C. Chou Doctoral Prize in IST

This prize recognizes outstanding doctoral dissertations in the broad area of information science and technology. The prize was established by Ben P.C. Chou's wife, June, and his son, Scott (B.S. '86), as a lasting tribute to his lifetime dedication to the pursuit of scholarly research and foregoing personal gain in favor of always doing the right thing for society.

Robert F. Christy Prize for an Outstanding Doctoral Thesis in Theoretical Physics

Awarded annually, this prize is given to a student who has produced an outstanding thesis in theoretical physics. Established in 2018, this prize honors the memory of Robert F. Christy, former provost and professor of theoretical physics.

Milton and Francis Clauser Doctoral Prize

An annual prize is awarded to the Ph.D. candidate whose thesis is judged by a committee of the Faculty Board to exhibit significant new work, ingenuity, and originality, and to have the greatest potential to open new avenues of human thought and endeavor. The Milton and Francis Clauser Doctoral Prize is made possible by gifts from the family and friends of these twin alumni, who received bachelor's degrees in physics in 1934, master's degrees in mechanical engineering in 1935, and doctorate degrees in aeronautics in 1937.

Donald Coles Prize in Aeronautics

The Donald Coles Prize will be awarded to the graduating Ph.D. student in aeronautics whose thesis displays the best design of an experiment or the best design for a piece of experimental equipment.

France Cordova Graduate Student Fund in Physics

The France Cordova Graduate Student Fund provides resources for one to three graduate students annually to support research-related expenses. The graduate student(s) shall be selected at the discretion of the Division Chair of Physics, Mathematics and Astronomy (PMA). Preference shall be given to student(s) studying broadly in areas in which Professors Gerry Neugebauer, Gordon Garmire and Tom Tombrello made contributions. Each awardee shall be recognized as either a Neugebauer, Garmire, or Tombrello Scholar and the name assigned to each student will be determined by the PMA Division Chair. The fund was established by France Cordova who received her Ph.D in physics from Caltech in 1979.

James A. Cullen Memorial Fellowship Fund

The Cullen Memorial Fellowship is a fund awarded annually to a graduate student or students who have demonstrated outstanding academic achievement in physics. The fellowship was established by the family of Caltech physics alumnus James Cullen (B.S. '46, Ph.D. '56).

Demetriades-Tsafka-Kokkalis Prize in Biotechnology or Related Fields

Awarded annually to a Ph.D. candidate for the best thesis, publication, or discovery in biotechnology or related fields at the Institute in the preceding 12 months. Winners are selected by the bioengi-

neering faculty. This award has been made possible by a gift from Anna Kokkalis Demetriades and Sterge T. Demetriades, Eng. '58.

Demetriades-Tsafka-Kokkalis Prize in Entrepreneurship or Related Fields

Awarded annually for the best business plan or proposal, start-up, thesis, publication, discovery, or related efforts by student(s) in entrepreneurship or related fields at the Institute in the preceding 12 months. This prize is made possible by a gift from Anna Kokkalis Demetriades and Sterge T. Demetriades, Eng. '58.

Demetriades-Tsafka-Kokkalis Prize in Environmentally Benign Renewable Energy Sources or Related Fields

Awarded annually to a Ph.D. candidate for the best thesis, publication, discovery, or related efforts in benign renewable energy sources or related fields at the Institute in the preceding 12 months. The prize is made possible by a gift from Anna Kokkalis Demetriades and Sterge T. Demetriades, Eng. '58.

Demetriades-Tsafka-Kokkalis Prize in Nanotechnology or Related Fields

Awarded annually to a Ph.D. candidate for the best thesis, publication, or discovery in nanotechnology or related fields at the Institute in the preceding 12 months. This prize is made possible by a gift from Anna Kokkalis Demetriades and Sterge T. Demetriades, Eng. '58.

Demetriades-Tsafka-Kokkalis Prize in Seismo-Engineering, Prediction, and Protection

Awarded annually to a Ph.D. candidate for the best thesis, publication, or discovery in seismo-engineering, prediction, and protection in the preceding 12 months. Winners are selected by the seismo-engineering faculty. The prize is made possible by a gift from Anna Kokkalis Demetriades and Sterge T. Demetriades, Eng. '58.

Constantin G. Economou Memorial Prize

Awarded to a chemical engineering graduate student distinguished by outstanding research accomplishments and exemplary attitude while fulfilling candidacy requirements for the Ph.D. degree.

Everhart Distinguished Graduate Student Lecture Series

The Everhart Lecture Series is a forum to encourage interdisciplinary interaction among graduate students and faculty, to share ideas about recent research developments, problems, and controversies, and to recognize the exemplary presentation and research abilities of Caltech's graduate students. Lecturers discuss scientific topics at a level suitable for graduate students and faculty from all fields while addressing current research issues. Each fall, three graduate-student lecturers are selected to present their work

as part of the Everhart Lecture Series based on each student's dynamic speaking skills, which capture the attention of and convey research material clearly to a diverse technical audience; ability to communicate their research field's broader importance; and impact on the scientific community through their research. Speakers receive an honorarium and recognition at graduation.

Lawrence L. and Audrey W. Ferguson Prize

Awarded to the graduating Ph.D. candidate in biology who has produced the outstanding Ph.D. thesis for the past year.

Henry Ford II Scholar Awards

The Henry Ford II Scholar Awards are funded under an endowment provided by the Ford Motor Company Fund. Each award will be made annually either to the engineering student 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 student to receive the award.

Graduate Deans' Award for Outstanding Community Service

This award is made annually to a Ph.D. candidate who, throughout their graduate years at the Institute, has made great contributions to graduate life and whose qualities of leadership and responsibility have been outstanding.

David and Barbara Groce Travel Grants in Physics, Mathematics, and Astronomy

The David and Barbara Groce Travel Fund was established by David, BS'58 (Physics), and his wife Barbara to partially pay the travel and meeting costs incurred by PMA graduate students attending and/or presenting research data at scientific meetings or conferences.

Hans G. Hornung Prize

This prize is awarded for the best oral Ph.D. defense presentation by a student advised by an aerospace faculty member. The committee to determine the winner is made up of current aerospace engineering students who attend the talks in order to make their recommendation.

Scott Russell Johnson Graduate Achievement Awards in Mathematics

The Scott Russell Johnson Achievement awards were established in 2001 by Steve and Rosemarie Johnson in memory of Steve's brother Scott who graduated in Math from Caltech in 1983. The Scott Russell Johnson Prize for Excellence in Graduate Study is given to continuing graduate students for extraordinary progress in research and excellence in teaching, or excellent performance as

a first-year graduate student. The Scott Russell Johnson Graduate Dissertation Prize in Mathematics is awarded for the best graduate dissertation in mathematics.

Abdul Kalam Prize in Aerospace Engineering

This prize is awarded to a student in the aerospace engineering master's program whose academic performance is exemplary and who shows high potential for future achievements.

John O. Ledyard Prize for Graduate Research in Social Science

The prize rewards the best third-year paper by a graduate student in Social Science or Behavioral Neuroscience. The prize is funded by Susan G. Davis in recognition of John O. Ledyard's dedication to developing graduate students as independent researchers and his service to the Division of the Humanities and Social Sciences. The prize is awarded annually by a committee of social science faculty.

The Herbert Newby McCoy Award

To support her husband's life-long interest in science, Mrs. McCoy designated that this annual award be made to a student or faculty member in the Division of Chemistry and Chemical Engineering of the California Institute of Technology making the greatest contribution of the year to the science of chemistry. The selection of the winner of this award shall be made by faculty of CCE and the President of the California Institute of Technology.

Dr. Nagendranath Reddy Biological Sciences Thesis Prize

Awarded to the graduating female Ph.D. candidate in the Division of Biology and Biological Engineering who has produced the most outstanding thesis in the biological sciences for the past year.

Eleanor Searle Prize in Law, Politics, and Institutions

The Eleanor Searle Prize was established in 1999 by friends and colleagues to honor Eleanor Searle. The prize is 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.

Ernest E. Sechler Memorial Award in Aeronautics

An award is made annually to an aeronautics student who has made the most significant contribution to the teaching and research efforts of the Graduate Aerospace Laboratories of the California Institute of Technology (GALCIT), with preference given to students working in structural mechanics. The Ernest E. Sechler Memorial Award in Aeronautics was established in 1980 in memory of Ernest E. Sechler, who was one of the first graduates of GALCIT and who then served as a GALCIT faculty member for 46 years. Throughout his career, Sechler was the faculty adviser for aeronau-

tics students. In addition, he made many contributions to structural mechanics in areas ranging from aeronautics to the utilization of energy resources.

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.

John Stager Stemple Memorial Prize in Physics

A prize is awarded annually to a graduate student in physics for outstanding progress in research as demonstrated by an excellent performance on the oral Ph.D. candidacy exam. John S. Stemple was a Caltech physics graduate student when he died; a memorial fund was established from contributions made by the community of Falls Church, Virginia, John's hometown.

R. Bruce Stewart Prize

The R. Bruce Stewart Prize for Excellence in Teaching is to be awarded annually to a graduate teaching assistant in physics who demonstrates, in the broadest sense, unusual ability, creativity, and innovation in undergraduate and graduate classroom or laboratory teaching. Named in honor of R. Bruce Stewart, who served as the Founder, Chairman and CEO of Arrowhead Research in Pasadena. Mr. Stewart was a successful entrepreneur who also started and funded over 18 companies in biotechnology, media technology licensing, direct marketing and early internet applications. Throughout his lifetime Mr. Stewart was a great friend to Caltech, supporting and often partnering in the work done by faculty and students. The prize is made possible by memorial gifts made by family and friends of R. Bruce Stewart.

Charles Wilts Prize

The Charles Wilts Prize is awarded annually for outstanding independent research in Electrical Engineering leading to a Ph.D. degree. This prize was established in 1992 to honor Charles Wilts, a member of the Electrical Engineering faculty from 1947–1975, who made substantial contributions to the Department of Electrical Engineering.

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.

Note: Prizes and awards may be subject to federal and state income tax.

SPECIAL REGULATIONS FOR GRADUATE OPTIONS

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AEROSPACE (Ae)

Aims and Scope of the Graduate Program

The Institute offers graduate programs in Aerospace leading to the degrees of Master of Science in Aeronautics and Space Engineering, and Doctor of Philosophy in Aeronautics and Space Engineering. The programs are designed to provide intense education in the foundations of the aeronautical and space sciences, with emphasis on research and analytical, computational, and experimental methods. Entering graduate students should have a thorough background in undergraduate mathematics, physics, and engineering science. Applicants for graduate study are also required to submit Graduate Record Examination scores with their applications.

In working toward a degree in Aerospace, a student may pursue major study in one of the following areas: physics of fluids, physics of solids and mechanics of materials, structural mechanics, space technology, computational solid mechanics, computational and theoretical fluid dynamics, aeronautical engineering and propulsion,

biomechanics of fluids and solids, technical fluid mechanics, control of aerospace systems and materials.

While research and course work in the Aerospace option at the Institute cover a very broad range of subjects, a choice of one of the above fields allows students to focus their activities while taking advantage of the flexibility offered by the breadth of interests of the Graduate Aerospace Laboratories (GALCIT).

In consultation with his or her adviser, a student will design a program of study in one of the above fields, consisting of the fundamental courses described in the regulations for the separate degrees listed below, and of electives selected from the list of Aerospace-related courses. This will ensure that the graduating student will be well-qualified for a career in aerospace and related fields.

Examinations, Committees, and Student Responsibilities

To help students achieve satisfactory progress in their academic pursuits, the Aerospace faculty provides for the following committee and individual support.

Upon beginning the first year of the Aerospace program, each student is assigned a faculty (course) adviser whose research field matches the interests of the student as described in the student's statement of purpose in his or her admissions application. The first-year adviser will guide the student in choosing a set of courses appropriate to the students' interests while ensuring the first-year academic requirements (see below) are met.

Students wishing to pursue studies leading to the Ph.D. must select and be accepted by a research adviser by the end of the spring term of the first year of residence and are required to pass a qualifying examination in the first term of the second year. Having passed the qualifying examination, the student pursues research under the supervision of the research adviser until he or she is ready to enter candidacy for the Ph.D. At this point, a four-member Candidacy Examination Committee that includes the student's research adviser is assembled and administers a Candidacy Examination to ensure the student has the appropriate knowledge and tools to successfully complete his or her chosen research activities. The Candidacy Committee is chaired by a faculty member other than the research adviser. The Candidacy Examination should be administered by the start of the second term of the third year of residence, but in any case, must be successfully completed by the end of that year in order to comply with Institute requirements.

Conferral of the Ph.D. degree is contingent on satisfactorily passing the thesis examination before a committee consisting of four examiners, which may, but does not need to, have the same membership as the Candidacy Committee. Students may find further information concerning special option requirements and the requisite option forms on the GALCIT website.

AE Master's Degrees

Master's Degree in Aeronautics and Master's Degree in Space Engineering

The master's degree program in aeronautics or space engineering is a one-year program that provides advanced training in the areas of aeronautics or space engineering beyond that covered in a four-year undergraduate program. The program consists of a set of five core courses (see details below). There is no research requirement, nor is a thesis required to obtain the degree. The courses required for the master's degree must be completed in one year.

Admission

Students whose highest qualification is a baccalaureate degree equivalent to that given by the Institute are eligible to seek admission to work toward the master's degree. Students are asked to submit course transcripts and letters of recommendation as well as GRE scores and evidence of English language proficiency as detailed in the graduate application. It should be noted that the graduate program at GALCIT is primarily focused on Ph.D.-level research and so priority in admission is given to those who plan to ultimately perform Ph.D.-level research.

Course Requirements

A program of study consists of courses totaling at least 135 units; of these, at least 81 units must be chosen from one of the following curricular tracks:

Aeronautics track

Two 27-unit course sequences chosen from:

- Fluid mechanics (Ae/APh/CE/ME 101 abc)
- Solid/structural mechanics (Ae/AM/CE/ME 102abc)
- Autonomy and control (CDS 131, Ae 103ab), 27 units

Experimental methods (Ae 104abc), 27 units.

Space Engineering track

One 27-unit course sequence chosen from:

- Fluid mechanics (Ae/APh/CE/ME 101abc)
- Solid mechanics (Ae/AM/CE/ME 102abc)

Autonomy and control (CDS 131, Ae 103ab), 27 units

Space engineering (Ae 105abc), 27 units.

Aerospace students in either the Aeronautics or Space Engineering track are required to enroll in a sequence of mathematics courses totaling 27 units appropriate to the student's chosen track and selected in coordination with their first-year advisers. Examples of appropriate courses include ACM/IDS 104, ACM 100ab, ACM 101ab, etc.

Finally, all first-year students are required to enroll in Aerospace Engineering Seminar (3 units Ae 150abc).

A grade of C or higher must be achieved in all the required classes unless they are only offered pass/fail, in which case a pass must be achieved in each class. For both the Aeronautics and Space Engineering master's degrees, the remaining 27 units are elective and are to be chosen from courses at Caltech that support the broader goals of the respective programs, subject to the approval of the student's adviser. Students must have a proposed program of courses approved by their adviser prior to registration for the first term of work toward the degree.

Admission to More Advanced Degrees

Students who successfully complete the requirements for the master's degree and who wish to pursue the more advanced degree of Doctor of Philosophy (Ph.D.) must file a petition to continue work toward the desired degree. All students working for the Ph.D. degree are expected to register for and attend the advanced seminar (Ae 208 abc) for a period of at least two years.

AE Degree of Doctor of Philosophy

Admission

Students with a baccalaureate degree equivalent to that given by the Institute are eligible to seek admission to work toward the degree of doctor of philosophy (Ph.D.) in Aeronautics or Space Engineering. Students are asked to submit course transcripts and letters of recommendation as well as GRE scores and evidence of English language proficiency as detailed in the graduate application.

Course Requirements

The course requirements for the first year of the Ph.D. degree are identical to those of the master's degree. Students admitted to graduate study for the Ph.D. degree must complete in their first year a course of study that would qualify them for the master's degree described above. The student may elect to receive the master's degree at the end of their first year after completion of these courses.

Research Adviser

Students wishing to pursue studies leading to the Ph.D. must select and be accepted by a research adviser preferably by the end of their third quarter but no later than the end of their first year of study and prior to taking the qualifying examination described below.

Qualifying Examination

After the first year of graduate study, the student must pass a qualifying examination. The objective of the qualifying examination is to determine if the student is properly prepared and qualified to pursue problems typical of Ph.D.-level research. The exam will cover the following subjects:

Aeronautics track

Two areas chosen from:

Fluid mechanics,
Solid/structural mechanics,
Autonomy and control.

Mathematics

Space Engineering track

One area chosen from:

Fluid mechanics,
Solid/structural mechanics,
Autonomy and control
Mathematics

The material covered in these examinations is at the same general level and breadth as covered in the corresponding first-year courses. The examinations are typically offered during one week in the first half of the fall term, in the second year of graduate residence at the Institute. A student is examined orally on all topics. In the event of an unsatisfactory performance, the examining faculty members may permit a repeat examination in the appropriate topics. The repeat examination must be scheduled prior to finals week of the winter term and must be completed before the end of the spring term of the same year.

Candidacy

To be recommended for candidacy for the Ph.D. in Aerospace, the applicant must

- have satisfactorily completed at least 135 units of graduate work equivalent to the above Master of Science program;
- pass, with a grade of C or better, 27 units of graduate-level mathematics courses beyond ACM 95/100, and ACM/IDS 104;
- complete (with a grade of C or better, or Pass) at least 45 units of Aerospace courses numbered Ae 200 or higher, or Ae/ME 118, Ae/ME 120, EE/Ae 157, Ae 159, Ae/Ge/ME 160 and Ae/CE 165ab, excluding research and seminars;
and
- complete three units of the advanced seminar Ae 208.

A proposed program conforming to the above regulations must be approved by the student's adviser and the option representative prior to add day of the first term of work toward the degree.

In addition to fulfilling these course requirements, the applicant must pass a candidacy examination in the third year of residence at the Institute. This exam should be administered by the start of the second quarter of the third year of residency. This examination aims at determining whether the student is successful in integrating formal course work into a mature understanding of fundamental engineering concepts, and at demonstrating his or her professional competence in applying these concepts to the problems being addressed in the course of their Ph.D. research.

Minor

No minor is required for the Ph.D. degree. Students are, however, encouraged to take advanced courses appropriate to their particular interests or pursue a minor in consultation with their adviser.

Foreign Languages

The student is encouraged to discuss with his or her adviser the desirability of studying foreign languages, but there is no formal foreign language requirement for the Ph.D.

Thesis and Final Examination

Prior to graduation, each candidate is required to give a seminar presenting the results of his or her thesis research. For final examination and thesis completion, see also the general degree requirements and the section on Examinations, Committees, and Student Responsibilities regarding Aerospace starting on page 360. A description of the Institute requirements for conferral of a Ph.D. are given on page 343.

Subject Minor

A student majoring in a field other than Aerospace may, with the approval of the option representative, elect Aerospace as a subject minor. A minimum of 54 units in subjects acceptable to the Aerospace faculty is required.

Problem and Grievance Resolution within Aerospace

Students may pursue several avenues for redress concerning personal and academic problems that may arise during their residency, as outlined by the Student Problem Resolution Process described earlier in the catalog. Should a student not wish to discuss the relevant issues with their adviser, the option representative and/or the director are always available to meet with the student. In addition, two other resources are available, one at the student and one at the faculty level. A student representative is elected annually by the Aerospace graduate students at or after the Information Session, which is part of Ae 150. In the event that the student representative has completed his or her Ph.D. studies before the election date and left the Institute, the student organizer for Ae 150 may be his or her replacement. A faculty member chosen by the Aerospace faculty to provide support for the students is available for student contact. The names of the current student and faculty support persons are available in the Aerospace office.

Educational Exchange Program with École Polytechnique

An educational exchange program is offered by the Aerospace option with École Polytechnique (EP). In this exchange program, students selected for participation from Caltech will enroll for one year at EP. Correspondingly, students selected for the program from EP will enroll for one year at Caltech. To be eligible to participate, Aerospace students must have completed one full year of study (for Caltech stu-

dents this is equivalent to the requirements for the M.S. degree) and agree that they will spend one full year at EP. First year (G1) graduate students enrolled in Caltech's doctoral Aerospace program will be apprised of the opportunity to participate in an educational exchange program at the master's level at EP. A maximum of two student(s) will be selected by the Aerospace faculty from the pool of students who express interest in this program. Caltech students will follow their first (master's) year at Caltech, and their second year in the second-year master's (M2) program at EP. Caltech students must fulfill the requirements of their first-year program and receive their Caltech M.S. diploma prior to proceeding to EP.

Caltech students must register at Caltech during the year spent at École Polytechnique and enroll in the special topics course Ae 240 – Educational exchange at École Polytechnique. This ensures that they maintain their standing as enrolled graduate students at Caltech. It is implied that classes taken at one institution cannot duplicate classes already taken at the other institution. The expectation is that Caltech students will return to Caltech after completing the EP program and continue with their doctoral studies at Caltech. Caltech students should be prepared to take the qualifying exams in the fall term when they return from EP. Caltech students participating in the Caltech/EP educational exchange program will be considered to be on detached duty from Caltech while at EP. A detached duty agreement will be executed for each student that spells out the terms and requirements for the detached duty.

APPLIED AND COMPUTATIONAL MATHEMATICS (ACM)

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Aims and Scope of the Graduate Program

Caltech's Computing & Mathematical Sciences department offers an interdisciplinary program of graduate study in applied and computational mathematics leading to the Ph.D. degree. This program is designed to give students a thorough training in fundamental computational and applied mathematics and to develop their research ability in a specific application field. The 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 by completion of the requirements for a Ph.D. degree in applied and computational mathematics.

The research areas and interests of the applied and computational mathematics faculty cover a broad spectrum, including non-linear dynamics, computational biology, numerical analysis and scientific computing, computational and theoretical fluid mechanics, theoretical materials science, multiscale computations and homog-

enization theory, computational methods for electromagnetics and acoustics, statistics, signal and image processing, probability theory and stochastic analysis, and dynamical systems and geometric mechanics. As reflected by the faculty research activities, there is a strong emphasis on computational methods for solving challenging problems arising from engineering and scientific applications.

Reflecting the interdisciplinary nature of the program, several different groups, in addition to the applied and computational mathematics faculty, contribute to the teaching and supervision of research. Students in applied and computational mathematics are expected to combine their basic mathematical studies with deep involvement in some field of application. Basic general courses are listed specifically under applied and computational mathematics, and these are to be supplemented, according to the student's interest, from the whole range of Institute courses in specific areas of physics, biology, engineering, etc.

A regular colloquium provides the opportunity for visitors, faculty, and students to discuss current research.

Admission

Each new graduate student admitted to work for the Ph.D. in applied and computational mathematics is given an informal interview on Thursday or Friday of the week preceding the beginning of instruction for the fall term. The purpose of this interview is to ascertain the preparation of the student and assist him or her in mapping out a course of study. The work of the student during the first year will usually include some independent reading and/or research.

Course Requirements.

All ACM students are required to take a total of 18 nine-unit courses at the graduate level (or the equivalent of 162 units) during their graduate study at Caltech. Among these 18 courses, the following core courses, typically taken during the student's first year of study, are required: ACM/IDS 101 ab, ACM 105, CMS/ACM/IDS 107, Ma 108 abc ACM/EE 106 ab, CMS 117, and an application elective course. The application elective course in the first year is selected, with the recommendation of the student's adviser, from among a wide range of courses offered by an outside option within the Institute. In addition, CMS 290 is required for all first year ACM graduate students during each term (fall/winter/spring). In the second and third years, students are expected to take graduate-level courses appropriate to their chosen research area. The remaining courses towards the 162 unit requirement would normally include graduate-level ACM or CMS courses such as CMS/ACM/IDS 113, ACM 201, 210, ACM/IDS 216, ACM/IDS 217, etc., as deemed appropriate to the student's research program, and which must be selected in consultation with the student's research adviser.

Students who have already taken some of the required courses

may use them to satisfy the course requirements, even though the units may not be used to satisfy the total unit requirement for the Ph.D. degree.

ACM Master's Degree

Students are not admitted to work toward the master's degree. The master's degree may be awarded to an ACM student only in exceptional circumstances. Of the 135 units of graduate work required by Institute regulations, at least 81 units of advanced graduate work should be in applied mathematics.

ACM Degree of Doctor of Philosophy

The Preliminary Examination.

Toward the end of the first year, all incoming students must take a preliminary examination administered by the faculty. Its purpose is to ensure a solid and broad knowledge in applied and computational mathematics, and in the event of a deficiency, to direct the students to necessary course and reading.

The Candidacy Examination

To be recommended for candidacy for the Ph.D. degree in Applied and Computational Mathematics, all students must, in addition to meeting the general Institute requirements and passing the preliminary examination, pass a candidacy examination administered by a committee that consists of at least four faculty, is approved by the option representative, and is chaired by the student's research adviser. The examination will ascertain the student's breadth and depth of preparation for research in the chosen area. The examination must be taken within the first three years of residence.

Advising and Thesis Supervision

Upon passing the preliminary examination, the student is required to choose a thesis supervisor who assumes the major responsibility in supervising the Ph.D. thesis. At the same time, an advising committee consisting of three faculty members is formed to help oversee the advising process. This committee should be formed no later than the third year of graduate study. The student's supervisor is part of this committee, but does not chair the committee. The student is encouraged to meet with the committee members informally for advice or suggestions. Joint supervision between two faculty members is also possible, as is seeking a thesis adviser outside the core applied and computational mathematics option, although in this case it is mandatory that an applied mathematics faculty member be nominated as a co-adviser.

Should a disagreement of any kind occur between the student and his or her supervisor as regards the timely completion of the thesis, the student is encouraged to direct his or her concerns to the committee chair. If this is not workable, the student should feel

free to consult with the option representative, the executive officer, or an applied and computational mathematics faculty member of the student's choice. If the student's concerns cannot be resolved through consultation with these individuals, the student is encouraged to pursue resolution of his or her concerns through other channels as outlined in Student Problem Resolution Process on page 42.

Final Examination

The final oral examination is held within four weeks after the submission of the thesis. The examination covers the thesis and related areas.

ACM Subject Minor

The group of courses must differ markedly from the major subject of study, and must include 54 units of advanced courses in applied mathematics and must not be simultaneously used for fulfilling a requirement of the second option. The qualifying courses exclude ACM95/100, although some flexibility is allowed depending upon the option of origin. The student must pass an oral examination whose subject is directly related to the material covered in the qualifying courses. This oral examination will be waived if the student has received a grade of A in every course.

APPLIED MECHANICS (AM)

Aims and Scope of the Graduate Program

Applied Mechanics (AM) research and study are offered through the Department of Mechanical and Civil Engineering (MCE). The degrees of Doctor of Philosophy (Ph.D.) and Master of Science (M.S.) are offered. In general, students who intend to work full-time toward the Ph.D. degree as a final degree objective are admitted to the applied mechanics graduate program. The M.S. degree is typically only awarded to students who pursue the Ph.D. degree in applied mechanics at Caltech and who do not already have an M.S. degree in applied mechanics.

The aim of the graduate program in applied mechanics at Caltech is to prepare students for research and professional practice in an era of rapidly advancing interdisciplinary technology. The program combines individual depth of experience and competence in a particular chosen major specialty, with a strong background in the basic and engineering sciences. It strives to develop professional independence, creativity, leadership, and the capacity for continuing professional and intellectual growth.

AM Preparation for the Graduate Program

Entering graduate students are expected to have a thorough background in undergraduate mathematics, physics, and engineering.

While a strong undergraduate program in applied mechanics should provide a suitable preparation, students who have not specialized in applied mechanics as undergraduates may also be admitted for graduate study. For example, an outstanding four-year undergraduate program in mathematics and sciences may provide a suitable background as well. The qualifications of each applicant will be considered individually, and, after being enrolled, the student will arrange his or her program in consultation with a member of the faculty.

AM Master's Degree

The degree of Master of Science in applied mechanics is only awarded to students who do not already have an M.S. degree in applied mechanics. The degree will be awarded upon request by students who have fulfilled the requirements. Only in exceptional cases is there admission to the M.S. program as the final degree objective.

A minimum of 138 units of courses numbered 100 or above, which meet the required master's program listed below, must be passed with a grade of at least C for completion of the master's degree in applied mechanics. All units must be taken for grades, except for courses offered only on a pass/fail basis. The M.S. degree in applied mechanics is typically completed within the first two years of residency at Caltech.

Each student's program must be approved by the adviser and option representative in mechanical and civil engineering before registering for the course.

Required Master's Program

- a) Graduate applied mechanics core (45 units). These units should provide a solid base for the student's engineering interest. The courses should be selected from the Core AM subjects listed under the Degree of Doctor of Philosophy Description and Requirements section.
- b) Mathematics, engineering, and research electives (63 units). Students who have not taken the equivalent of ACM 100 ab are required to take ACM 100 ab for 24 units. Research up to a maximum of 27 units.
- c) Free electives (27 units). Any course with a number of 100 or greater, may be selected, except that research units may not be included.
- d) Graduate Engineering Seminar, AM/CE/ME 150 abc (3 units).

AM Degree of Doctor of Philosophy

The Ph.D. degree in applied mechanics is focused on research. Study and research programs for the Ph.D. degree are individually planned

to fit the interests and background of the student. A comprehensive research project resulting in an original contribution to the field which is documented by a thesis is required. Institute requirements for the Ph.D. degree are described in the section on degree requirements. A minimum of three academic years in residence as a graduate student are required by the Institute, and two or more additional years are usually needed for preparation of the thesis.

Advising and Thesis Supervision

An interim adviser is appointed for each student upon admission to a graduate degree in applied mechanics. The interim adviser will serve as the primary mentor until the student finds a research adviser. It is the responsibility of the student to find an academic and research adviser within three terms of graduate residence at Caltech. In consultation with the adviser, the student must form a Ph.D. Thesis Advisory Committee within four terms of graduate residence at Caltech. This committee shall consist of at least three members of the Caltech professorial faculty, with at least two members from the faculty in mechanical and civil engineering. The committee shall meet as requested by the student. Further, the committee shall meet annually to review progress and to approve the registration of the student beyond the fifth year of graduate residence at Caltech.

The adviser and the Thesis Advisory Committee provide the majority of mentoring to the student. In addition, the option representative and other members of the faculty are always available to provide advice and mentoring on any aspect of research, progress toward the Ph.D., future careers, and other aspects of life in graduate school and as a professional scientist.

Admission to Candidacy

To be recommended for candidacy for the Ph.D. degree in applied mechanics, the student must, in addition to meeting the general Institute requirements, do the following:

- Obtain the agreement of a professorial faculty member to serve as his or her academic and research adviser before the end of the third term of graduate residence at Caltech. In consultation with the adviser, the student must form a Ph.D. Thesis Advisory Committee before the end of the fourth term. This committee shall consist of at least three members of the Caltech professorial faculty, with at least two members from the faculty in mechanical and civil engineering.
- Pass both subject and research components of the oral candidacy examination before the end of the eighth term of graduate academic residence at Caltech. If the student has chosen a subject minor, an examination on the subject of that program may be included at the request of the discipline offering the subject minor.

- Complete a minimum of 195 units of courses numbered 101 or above, that meet the required Ph.D. program listed below. All units must be taken for grades and passed with a grade of at least a C, except for courses offered only on a pass/fail basis. The course work towards the Ph.D. degree in applied mechanics is typically completed within the first three years of residency at Caltech.

The faculty will evaluate the student's research progress, class performance, adviser's input, and oral candidacy exam results to determine whether a student will be admitted to or be able to maintain candidacy for the Ph.D. degree.

Required Ph.D. Program

- Applied Mechanics Core Subject* (45 units): Course work in core subjects selected from the list below; pass with a grade of at least C:
Ae/APh/CE/ME 101abc, Ae/AM/CE/ME 102abc, AM/CE 151, Ae/Ge/ME 160ab, ME/CE 163, Ae/CE 165ab, ME/CE/Ge 174, CE 181ab, Ae/AM/MS/ME 213ab, Ae/AM/CE/ME 214ab, Ae 220, Ae/CE 221, Ae/AM/ME 223, AM/CE/ME 252, ME/Ge/Ae 266ab.

The student may petition the mechanical and civil engineering option representative to accept alternate subjects or areas. These changes should retain core applied mechanics knowledge, should not be a sub-specialty of one of the listed areas, and should represent sufficient breadth. The approval is not automatic; such petitions are submitted rarely and many have been denied in the past. The petition must be submitted to the option representative and approved before the student registers for the course.

- Electives or Minor* (63 units): Additional engineering or science courses with course number 101 or above. Pass with a grade of at least C, courses that are approved by the thesis advisory committee. These courses are intended to provide further depth and incorporate breadth. These units can be used to satisfy a minor requirement in another option.
- Advanced mathematics or applied mathematics* (27 units): Pass with a grade of at least C, chosen in consultation with adviser from the following list: ACM 101 or higher, CDS 232, Ma 108 or higher, Ph 129. The requirement in mathematics is in addition to the requirements above.
- Graduate engineering seminar* (6 units): six terms of AM/CE/ME 150 abc, within twelve terms or, 3 years, in residence at Caltech.
- Research* (54 units). Successfully complete at least 54 units of research and demonstrate satisfactory research progress.

Registration Beyond the Sixth Year of Graduate Residence

The annual approval of the Ph.D. dissertation supervision committee is necessary for registration beyond the twenty-fourth academic term of graduate residence at Caltech.

Thesis and Final Examination

The thesis examination will be given after the thesis has been formally completed. This examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in the specialized field of research. The format of the examination can be chosen from the following two options, by the student, in consultation with their research adviser: (i) a public seminar presented by the candidate, with an open question period, followed by a private examination by the examining committee or (ii) a private presentation to the examining committee followed by the examination, with a public seminar on another date. The examining committee shall consist of a minimum of four voting members, three of whom must be Caltech faculty; two members must be from MCE. The thesis defense committee shall be chaired by a committee member who is an MCE Caltech professorial faculty member and not the student's adviser.

AM Subject Minor

A student majoring in another branch of engineering or another division of the Institute may, with the approval of the faculty in the department of mechanical and civil engineering and the faculty in his or her major field, elect applied mechanics as a subject minor. The program of courses must differ markedly from the major subject of study or research, and must consist of at least 54 units of advanced courses (101 or above) approved by the faculty in mechanical and civil engineering.

APPLIED PHYSICS (APh)

Aims and Scope of the Graduate Program

Applied Physics is a broad field of study that lies at the intersection of physics and many other fields of science and engineering. The applied physics option at Caltech is accordingly a highly multi-disciplinary program that is designed to train students in a broad spectrum of physics and engineering fields at an advanced level. Moreover, it is our goal to cultivate abilities in our graduates to apply this knowledge throughout their lives so as to make technological and scientific breakthroughs at the edge of current knowledge.

APh Preparation for the Graduate Program

Students admitted for graduate study can enter from a broad range of disciplines, but are expected to have a rigorous background in undergraduate mathematics, physics, and engineering. An outstanding four-year undergraduate program in mathematics and sciences may provide a suitable background as well. The qualifications of each applicant will be considered individually. After enrollment, the student will arrange a course of study and research in consultation with members of the faculty and the applied physics option representative.

APh Description of the Degree of Doctor of Philosophy (Ph.D.)

To receive the doctoral degree in Applied Physics students must demonstrate the ability to formulate and execute an original program of scientific study. As part of this, a doctoral candidate is expected to develop a deep understanding in a chosen field of specialization; to develop tools with which to assess problems outside one's field of specialization; to develop rigor and strength in the physical sciences for self-education beyond formal training; and to develop skills to become a productive member of the community of scholars. All students wishing to enter the program must complete a series of preparatory courses, followed by an oral candidacy exam in which the student describes their proposed topic of research and is examined on their knowledge of course subject matter. Upon passing the candidacy examination, students work towards completion of a thesis in consultation with their research adviser. The doctoral degree is awarded upon approval of a written thesis by a faculty committee, and successful defense of the thesis in a final oral examination. There is no separate master's program in applied physics. However, with the approval of the student's adviser and the applied physics option representative, the degree of Master of Science in Applied Physics may be awarded after the fulfillment of the course requirements described below.

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APh Advising and Thesis Supervision

An interim adviser is appointed for each student upon admission to the graduate program in applied physics. Typically, this person is the applied physics option representative. In consultation with the interim adviser the student will determine a course schedule and identify a faculty research adviser. This most often occurs within the first six months of graduate residence. The faculty adviser is the student's primary mentor and the student will work in the adviser's research group to formulate and execute a plan of study leading to the thesis. In consultation with their research adviser, the student will also form a Ph.D. Thesis Advisory Committee. This four-member committee should include the student's adviser and at least three members of the Caltech professorial faculty from

either the applied physics or physics options. The Thesis Advisory Committee will conduct the qualifying examination and also approve the thesis and conduct the thesis defense. The membership of this committee may change between the time of the qualifying exam and the final defense.

APh Requirements for Candidacy to the Ph.D. Degree

To be recommended for candidacy for the Ph.D. degree in Applied Physics, a student must demonstrate mastery in the following five areas of pure and applied physics:

- Classical Physics: Mechanics and Electromagnetism
- Quantum Mechanics
- Mathematical Methods
- Statistical Physics and Thermodynamics
- Biophysics, Optical Physics, Hydrodynamics, Plasma Physics, or Solid-State Physics

A. Graduate Coursework toward Candidacy

In partial fulfillment of the “mastery” requirement a student must successfully complete a minimum of 135 units of courses numbered 101 or above from the course schedule. In addition, 4 units of APh 110ab must also be completed. All courses must be passed with a grade of at least a C, except for courses offered only on a pass/fail basis. Students must also complete the degree progress report online upon completion of their courses.

Note: Items in brackets represent optional replacements.

	<i>Total Units</i>
1. Classical Mechanics and Electromagnetism	27
Ph 106 a (9 units)	
Ph 106 b (9 units)	
Ph 106 c (9 units)	
2. Quantum Mechanics	27
Ph 125 a [Ch 125 a] (9 units)	
Ph 125 b [Ch 125 b] (9 units)	
Ph 125 c [Ch 125 c] (9 units)	
3. Mathematical Methods	24–27
ACM/IDS 101 a [Ph 129 a] (12/9 units)	
ACM/IDS 101 b [Ph 129 b] (12/9 units)	
[Ph 129 c] (9 units)	

4. Statistical Physics and Thermodynamics**27**

APh/MS 105 a [Ph 127 a or Ae/ME 118 or ChE/
Ch 165] (9 units)

APh/MS 105 b [Ph 127 b or ChE/Ch 164] (9 units)

APh 105 c/MS [Ph 127 c] (9 units)

5. One of the following course sequences in Biophysics, Optical Physics, Hydrodynamics, Plasma Physics, or Solid State Physics:

(It is recommended that students complete one full sequence from the courses listed below i.e. every term of a single course. Exceptions may be made after consultation with the option representative.)

Fluid Mechanics**27**

Ae/APh/CE/ME 101a (9 units)

Ae/APh/CE/ME 101 b (9 units)

Ae/APh/CE/ME 101 c (9 units)

Solid-State Physics**27**

APh 114 a [Ph 135] (9 units)

APh 114 b [Ph 223 a] (9 units)

APh 114 c [Ph 223 b] (9 units)

**Physics of Transport Phenomena
in Hydrodynamic Systems****24**

APh/Ph 115 (12 units)

APh/Ph/Ae 116 (12 units)

Plasma Physics**27**

APh 156 a (9 units)

APh 156 b (9 units)

APh 156 c (9 units)

**Physical Biology of the Cell,
Physical Biology Lab**

24

APh/BE 161 (12 units)

APh/BE 162 (12 units)

**Electromagnetic Theory, Light Interaction with
Atomic Systems – Lasers, Special Topics in
Photonics and Optoelectronics**

27

APh 130 (9 units)

APh 131 (9 units)

APh 132 (9 units)

**Physics of Semiconductors and
Semiconductor Devices**

9

APh 183 (9 units)

Quantum Electronics

27

APh 190 a (9 units)

APh 190 b (9 units)

APh 190 c (9 units)

First year students are also required to take APh 110ab, a two-term seminar course in which faculty review their research areas and ongoing research work in their group.

Total Units

**Faculty Presentation Seminar for
1st Year Graduate Students**

4

APh 110 a (2 units)

APh 110 b (2 units)

In addition to work in the classroom, students must complete a minimum of 27 units of laboratory or reading research through APh 200.

Applied Physics Research

APh 200

27

Students entering the program with advanced preparation may choose either to substitute more advanced courses in the topical areas shown or demonstrate competency by successfully passing both the midterm and final examinations. In such cases, students may petition the Applied Physics option representative to accept alternate subjects or areas. These changes should retain core applied physics knowledge, and maintain sufficient breadth. All such petitions must be submitted to the option representative and approved before the student registers for the course.

Coursework towards the Ph.D. degree in Applied Physics is normally completed within the first two years of graduate residency.

B. Candidacy Examination

To fulfill the requirements for candidacy all students must pass an oral examination after completing their coursework. This examination must be taken before the beginning of the student's third year in residence. Students will be expected to deliver a half-hour oral presentation giving a prospectus on their proposed thesis research. Following questions on the research prospectus, a more open-ended set of questions will be posed to the student by the committee members to test general proficiency in the five areas of pure and applied physics listed above. Students who fail the oral examination on their first attempt will be given additional guidelines for further study and an opportunity to retake the examination a second and final time if the committee so recommends. Should a student fail the oral examination a second time, he/she cannot continue with doctoral studies leading to the Ph.D. Upon recommendation of the examining committee, however, the student may be granted a master's degree. Annual approval of the applied physics option representative is necessary for registration beyond the third year of graduate residence if the student has not completed the candidacy examination.

Students who fulfill the requirements above will be recommended for candidacy to the doctoral program and a master's degree (if applicable) in applied physics.

APh Ph.D. Thesis Requirements

The candidate is to provide a draft copy of his or her completed thesis to the members of the examining committee (typically the same as the thesis committee) at least two weeks before the final oral examination. The date of the examination and the composition of the examining committee will not be approved by the Dean of Graduate Studies until the thesis is submitted in completed form, i.e., ready for review by

the Dean, the members of the thesis committee, and the Graduate Office proofreader. Registration is required for the term in which the thesis defense is taken, but is not normally allowed beyond the last date of the term. For more information, please see the section entitled “Information for Graduate Students” in the Caltech catalog.

APh Ph.D. Final Examination

The candidate shall undergo a final broad oral examination (thesis defense) in the field, to include the subspecialty represented by the thesis and the significance of its findings to the field. This oral examination will be administered at least two weeks after the doctoral thesis has been presented in final form so that the examining committee has sufficient time to review its content. This examination must be taken at least three weeks prior to the date on which the degree will be officially conferred.

APh Registration Beyond the Sixth Year of Graduate Residence

The annual approval of the student’s Thesis Advisory Committee is necessary for registration beyond the twenty-fourth academic term of graduate residence at Caltech.

APh Subject Minor

Graduate students majoring in other fields may elect a minor in applied physics. In addition to general Institute requirements, the student must complete, with a grade of C or higher, 81 units of courses in applied physics above the 100 level, excluding APh 200. The minor is also subject to the following conditions:

- Students cannot use courses required by their major option in fulfillment of this requirement.
- Students interested in a minor must receive prior approval from the option representative in applied physics, who will review and approve the proposed course of study.
- It is recommended that this course of study include advanced courses spanning different subfields of applied physics.

ASTROPHYSICS (Ay)

Aims and Scope of the Graduate Program

The primary aim of the graduate astrophysics program at Caltech is to prepare students for creative and productive careers in astrophysical research and a variety of other challenging vocations. The astrophysics program emphasizes independent research by graduate students, who are free to pursue study in virtually any area of astrophysics. The opportunity exists to take advantage of the many observational facilities owned and operated by Caltech (see page 117).

Ay Admission

Incoming students should have a strong background in physics, and although a good preparation in astronomy is helpful, this is not required for admission to the graduate program. While the Graduate Record Examination scores for verbal and quantitative aptitude tests and the advanced test in physics are not mandatory, they are strongly recommended, especially for the candidates who did not have an adequate opportunity to engage in research as undergraduates, and/or from the countries or institutions where we may not be familiar with the grading systems.

Ay Master's Degree

While the option does not offer a master's degree program in itself, students who fulfill the general Institute requirements for such a degree, and the specific option requirements (see below), can receive a master's degree, either en route to a final Ph.D. degree if admitted to candidacy, or as a terminal degree if the candidacy requirements are not met.

The choice of astronomy and other science elective courses must be approved by the option representative. At least 36 units of the 135 units must be selected from Ay 121–127. The courses Ph 106, Ph 125, and Ph 129 may be required of those students whose previous training in some of these subjects proves to be insufficient. At least 27 units of advanced courses in fields other than astronomy are required.

Ay Degree of Doctor of Philosophy

Astrophysics Program

The student's proposed overall program of study must be approved by the option representative during the first year. The following are required of all students for candidacy: Ay 121, Ay 123, Ay 124, Ay 125, Ay 126, and Ay 127. The student should take these courses in the first year. Students must also take at least one term of Ay 122 unless exempted. Also required are research and reading projects. Credit for this work will be given under courses Ay 142 and Ay 143. The above courses must be passed with a grade of B– or better.

Physics Program

The student's program during the first two years of graduate study should include at least 36 units of physics courses, exclusive of Ph 106, Ph 125, and Ph 129, and should include Ph 136 a and Ph 136 b, unless specifically exempted. Suggested courses include, but are not limited to: Ph 101, Ph 105, Ph/Aph 118 a, Ph 127 b, Ph 135, Ph 236, Ph 237. Courses cross-listed with Ay (e.g. Ph/Ay) do not count toward the physics unit requirement, unless specifically allowed by prior consultation between the student, the instructor, and the option representative. Students in radio astronomy may substitute an advanced course in electrical engi-

neering or applied mechanics for up to 9 of the required 36 units of physics, and students in planetary astronomy may similarly substitute an advanced course in geophysics or geochemistry for up to 9 of the required 36 units of physics. The requirement may be reduced on written approval for students who take substantial numbers of units in Ph 106, Ph 125, and Ph 129. Theoretical astrophysics students should include at least 54 units of physics or applied mathematics courses in their programs. No more than 18 of the 36 units may be taken P/F; all others must be passed with a grade of C or better. In their third year and above, students are encouraged to take additional advanced astronomy and physics courses, but there is no specific requirement, and they do not count towards the 36 units of physics.

Other Requirements

An ability to explain concepts and to verbally present one's work is vital to a successful career in research and/or teaching. To this end, all graduate students in astrophysics are required to serve as teaching assistants during their second year, and to make oral presentations as part of the course Ay 141, 3 terms of which must be taken every year by all students beginning in their second year.

The Minor

It is recommended that students take a subject minor in physics. Other fields in which subject minors are taken include geology or engineering, depending on the student's field of specialization.

Language Requirement

Although the department believes that knowledge of foreign languages is generally useful, there is no formal foreign-language requirement. However, graduate students for whom English is a second language may be required to demonstrate fluency in oral and written English at the time of their candidacy exam. The examining committee will administer a test when this is deemed necessary.

Admission to Candidacy

To be recommended for candidacy for the Ph.D. degree in astrophysics, a student must, in addition to meeting the general Institute requirements:

- complete satisfactorily 36 units of research (Ay 142) or reading (Ay 143);
- pass satisfactorily, or by special examination, the required astrophysics courses (see above);
- pass a general oral examination (see below);
- pass a thesis-related examination (see below);
- complete the physics course requirement (see above);
- satisfy a teaching requirement (generally two terms as a GTA);

- fulfill the language requirement if applicable (see above); and
- be accepted for thesis research by a member of the faculty.

In fall of their second year, all students are required to take a general oral qualifying examination. Students will be examined on the substance and status of, as well as their performance on, a research project, which should be started not later than the summer following the first year. They will further be examined on their broad understanding of current topics in, and fundamentals of, astrophysics. Both of these aspects of the examination are intended to evaluate the candidate's aptitude for a research career in astrophysics. In addition, at the discretion of the executive officer, students who have not done well in one, or at most two, areas covered in the Ay 120 course series during their first year will be retested in these areas during the examination. Students must pass all of the aspects of this examination, as judged by the faculty committee conducting it, in order to continue in the Ph.D. program.

Students who do not meet the minimum grade requirements in the Ay 121–127 series, or who do not pass the general candidacy examination described above, will not be able to continue in the Ph.D. program. They may receive a terminal master's degree, provided that they fulfill the requirements for it (see above).

Advising and Thesis Supervision

By the summer of their first year, students should be spending most of their time on research. During their first two years, students are free to work with any faculty they wish, on one or more projects. However, by the summer of their second year at the latest, they should have defined a thesis project and been accepted by a faculty research adviser for that project (in cases where the thesis involves multiple projects, a second faculty adviser may supervise part of the research, but one must be selected as primary adviser). An oral candidacy exam dealing with the student's proposed thesis research should be taken before the end of the third year. The date and time of the exam are the responsibility of the student to arrange. The examining committee is chosen by the executive officer in consultation with the student's adviser. It will stand until the final examination, and be charged with ensuring that satisfactory progress toward the Ph.D. is being made.

If the candidate does not pass the oral candidacy exam, then the examining committee may at its discretion offer the candidate a second oral examination. This examination must be successfully completed by the end of the third term of the third year.

After the oral candidacy exam, the adviser and the student together have primary responsibility for the student's progress and career development. To ensure that these remain on course, both student and adviser must submit annual progress reports to

the executive officer (or in the case of a conflict of interest, to the astrophysics option representative or the division chair). If at any stage the student, the adviser, or the executive officer feels that there are serious problems developing, they may consult in confidence with the astrophysics option representative, the executive officer, or the division chair. They may also request a meeting of the oral candidacy exam committee or seek the advice or help of other faculty members. Students may also seek confidential advice and help from the Student Wellness Services.

Final Examination

A final draft of the thesis must be submitted at least six weeks before the commencement at which the degree is to be conferred. At least two weeks after submission of the thesis, the student will be examined orally on the scope of his or her thesis and its relation to current research in astrophysics. The examination will be conducted by a committee selected in the same way as the oral candidacy committee. The examination should occur before the end of the fifth year.

Typical Timeline

Year 1: Ay 121, Ay 123–127; at least two advanced physics courses; reading and independent study. Begin research.

Year 2: Early fall—general oral qualifying examination. Research projects; select thesis and adviser. Fulfill teaching requirement. Complete 36 units of physics (54 for theorists); a term of Ay 122 if applicable; optional advanced astronomy courses. Ay 141.

Year 3: Take oral candidacy exam on thesis before end of second term. Annual report from student and adviser. Ay 141.

Optional Advanced Courses:

Year 4: Annual report from student and adviser. Ay 141.

Year 5: Annual report from student and adviser. Ay 141. Complete Ph.D. thesis before end of year 5. Final oral examination.

Ay Subject Minor

The program for a subject minor in astrophysics must be approved by the department before admission to candidacy. In addition to general Institute requirements, the student must complete satisfactorily, with a grade of C or better, 45 units in advanced courses in astronomy.

BIOCHEMISTRY AND MOLECULAR BIOPHYSICS (BMB)

Aims and Scope of the Graduate Program

An integrated approach to graduate study in biochemistry and molecular biophysics has been organized primarily by the Divisions of Biology and Biological Engineering (BBE) and Chemistry and

Chemical Engineering (CCE). The curriculum is designed to provide a broad background in biochemistry and biophysics of macromolecules and molecular assemblies, in addition to an appropriate depth of knowledge in the field selected for the Ph.D. thesis research.

BMB Admission

The option in Biochemistry and Molecular Biophysics is open to students with undergraduate degrees in biochemistry, biology, chemistry, biophysics, physics, engineering, and related areas. Applicants for admission may submit results from the Graduate Record Examination. Applicants whose native language is not English are required to submit results of the TOEFL exam and, after admission, are required to satisfy the English language requirements of the Institute.

BMB Master's Degree

Students are not admitted to work toward the M.S. degree. An M.S. degree may be awarded only in special circumstances, provided Institute requirements are met, and is typically conferred after the end of the second year of residence.

BMB Degree of Doctor of Philosophy

The Option Representative will counsel and oversee the student's progress upon admission to the graduate program. During the first year of graduate study, students are required to participate in the BMB 202 seminar course. Additionally, as noted below, the option offers a series of courses that will expose the student to contemporary issues in biochemistry and molecular biophysics, and to the tools and methods that are essential for research in this area. Research advisers are normally selected at the end of spring quarter of the first year. Students are required to take six advanced courses of nine or more units that are appropriate for their particular research interests (as determined by the Option Representative).

Teaching

All students are to serve as teaching assistants for one quarter per year when they are in residence, through the fourth year. In addition to serving an educational purpose, funds for the TA assignments are a component of the stipend. A student may be excused from up to two years of the TA requirement if they obtain funds from a fellowship or obtain research adviser support. Outside funds, such as previous TA positions prior to starting the Ph.D. program, may be considered as satisfying the requirement upon approval by the Option Representative.

Laboratory Rotations

In consultation with the Option Representative and individual pro-

fessors, students will choose three laboratories to do one term research projects during their first year of residence. These laboratory rotations are designed to provide students with an introduction to different areas of biochemistry and molecular biophysics along with identifying a lab for thesis research. It is possible to waive the third rotation by petitioning the Option Representative.

Admission to Candidacy

By the end of the sixth term of residency, the student will take an oral examination to assess mastery of the field of biochemistry and to evaluate research progress. As part of this examination, each student will submit a written research report summarizing the progress in their research, and an original research proposal in a field outside the student's chosen field of research. A candidacy examination committee of four to five faculty (including the adviser) will be assembled by the student in consultation with their adviser and approved by the Option Representative. The chair of the committee should be identified at this time and should be a member of the Biochemistry and Molecular Biophysics option who is not the thesis adviser. In addition to satisfactory completion of the Candidacy exam, admission to Candidacy requires satisfactory completion of six advanced courses of nine or more units. Upon admission to candidacy, the faculty committee will become the thesis advisory committee. Students are required to meet annually with their thesis advisory committee to evaluate research progress. This committee will also serve as the Ph.D. thesis examination committee. A fifth member may be added at this time. After Candidacy, a student will meet annually with the thesis committee to assess progress.

Thesis and Final Examination

Thesis research will be carried out under the direction of one or more faculty members in the biochemistry and molecular biophysics option. The thesis defense will consist of a thesis seminar, followed by an examination by the Ph.D. thesis committee.

BIOENGINEERING (BE)

Aims and Scope of the Graduate Program

Bioengineering research at Caltech focuses on the application of engineering principles to the design, analysis, construction, and manipulation of biological systems, and on the discovery and application of new engineering principles inspired by the properties of biological systems. Areas of research emphasis include: biodevices, bioimaging, bioinspired design, biomechanics, biomedical engineering, cell and tissue engineering, molecular programming, synthetic biology, and systems biology. The goal of the doctoral program is to prepare students to become leading scientists and engineers in academia and industry. The graduate program aims

to educate students to be highly competent in their chosen area of research, but also provide them with a broad knowledge foundation in bioengineering. By graduation, students are expected to have a working knowledge of bioengineering in general and an in-depth knowledge of their chosen area, have independently planned and conducted research experiments in their chosen area, and successfully defended their thesis work in an open forum.

BE Master's Degree

Students are not admitted to work toward the M.S. degree. In special circumstances, the M.S. degree may be awarded, provided Institute requirements are met.

BE Degree of Doctor of Philosophy

In addition to satisfying the general Institute requirements, candidates for a Ph.D. in bioengineering at Caltech must satisfy the following requirements:

Course Requirements

Coursework requirements provide maximum flexibility in building on undergraduate training and complementing the research activities of each student. Students take six electives (one-quarter courses totaling at least 54 units; grade of B or higher in each course) selected in consultation with the student's adviser and the option representative. To maximize the opportunity for research during the early stages of the graduate career, coursework may be spread over the first and second years.

To assist in the selection of a research area, to foster interactions within the entering class, and to discuss ethical guidelines for scientific research, first-year students participate in three discussion courses totaling 9 units: current research topics in Caltech bioengineering labs (BE 167, first term); Reading the Bioengineering Literature (BE 201, second term); Responsible Conduct of Research (Bi 252, third term). A second term of BE 201 is also required for second year graduate students.

Bioimaging and biomedical devices electives: AM/CE 151 ab, APh 109, APh/EE 130, APh/EE 132, BE/EE/MedE 189 ab, Bi/BE 177, Bi/BE 227, EE/APh 131, EE/BE/MedE 185, EE/MedE 187, Ph 106 abc, Ph/APh/EE/BE 118 abc.

Biomechanics and bioinspired design electives: Ae/APh/CE/ME 101 abc, Ae/AM/CE/ME 102 abc, Ae/BE 242, BE/Bi/MedE 106, BE 159, ChE 103 abc, ChE 151 ab, ChE/Ch 164, ChE 174, MedE/BE/Ae 243, Ph 127 abc.

Synthetic biology, systems biology, molecular programming, and cell and tissue engineering electives: BE 150, BE 153, BE 159, BE/APh 161, Bi 117, Bi 145 ab, ChE/BE 163, BE/CS/CNS/Bi 191ab, ChE 130.

Biology electives: BE 150, Bi/Ch 110, Bi/Ch 111, Bi 114, Bi 115,

Bi 117, Bi 118, Bi 122, Bi/BE 129, Bi 145 ab, BE 153, BE 159, BE/APh 161, Bi/CNS 150.

Math electives: ACM 100 ab, ACM/EE/IDS 116, ACM/ESE 118, AM 125 abc, ChE 105, CDS 110, CDS 140.

Research

The flexibility of the coursework requirements enables research to be the primary activity from the very first term in residence. Students are encouraged to do two or more research rotations during the first year to sample research activities in multiple labs before selecting a Ph.D. adviser. Rotations are arranged by contacting individual faculty.

Adviser Selection

Each student must select a Ph.D. adviser by the end of the spring term of the first academic year. Advisers may be any Caltech faculty member working in an area related to bioengineering.

First Year Conversation

Before the end of the spring term of the first year in residence, each student meets with a faculty committee for a discussion of first-year progress and second-year plans. The committee must be composed of three faculty, plus the Ph.D. adviser(s), including a minimum of two Bioengineering faculty. The student will give a brief presentation on research progress and future plans, as well as discuss fundamentals related to the research area.

Admission to Candidacy

By the end of the spring term of the second year in residence, each student must complete the coursework requirement, prepare a candidacy report, and pass an oral candidacy exam. The report should be brief, describing research progress to date and outlining plans for the remaining doctoral research. The candidacy report should be submitted to the committee members one week before the oral exam. The committee must be composed of three faculty, plus the adviser(s), including a minimum of two Bioengineering faculty. The oral candidacy exam will include presentation of research progress, presentation of a proposed outline for the thesis, and questioning on fundamentals related to the research area. Students that complete the coursework requirement, prepare a candidacy report, and pass the oral candidacy exam will be recommended for candidacy. Students that are not admitted to candidacy by the end of the second year in residence will not be permitted to register in subsequent terms except with special permission from the option representative.

Thesis Advisory Committee Meetings

Once a student has been admitted to candidacy, each doctoral student will select a Thesis Advisory Committee (TAC). The com-

mittee must be composed of three faculty, plus the adviser(s), including a minimum of two Bioengineering faculty. This committee should meet at least once each year for the remainder of the student's time at Caltech.

Thesis Examination

A final oral examination will be given after the thesis has been formally completed. The exam will consist of a public research presentation followed by a private defense with an exam committee. The committee must be composed of three faculty, plus the adviser(s), including a minimum of two Bioengineering faculty. The thesis examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in his or her specialized field of research.

BE Subject Minor

A student may, with the approval of the Bioengineering graduate option representative, elect a subject minor in Bioengineering. Such a program shall consist of 45 units of upper division course work in Bioengineering, with each course passed with a grade of C or better. Courses used to satisfy course requirements in the student's major option may not be used to satisfy the minor requirements. Approval of each program must be obtained from the Bioengineering graduate option representative.

BIOLOGY (Bi)

Aims and Scope of the Graduate Program

Graduate students in biology come with very diverse undergraduate preparation—majors in physics, chemistry, mathematics, or psychology, as well as in biology and its various branches. The aims of the graduate program are to provide, for each student, individual depth of experience and competence in a particular chosen major specialty; perception of the nature and logic of biology as a whole; sufficient strength in basic science to allow continued self-education after formal training has been completed and thus to keep in the forefront of changing fields; and the motivation to serve his or her field productively through a long career.

In accordance with these aims, the graduate study program in biology includes the following parts: (a) the major program, which is to provide the student with early and intense original research experience in a self-selected subject of biology, supplemented with advanced course work and independent study in this subject; and (b) a program of course work designed to provide well-rounded and integrated training in biology and the appropriate basic sciences, which is adjusted to special interests and needs. An individual program will be recommended to each student in a meeting with the student's advisory committee (see below). The Division of

Biology does not encourage applications from students who have pursued undergraduate study in biology at the Institute, because the broader perspective to be gained from graduate study in a different setting is considered to be essential for the full development of each student's potential. Exceptions to this policy may be considered by the faculty of the division if there are circumstances that indicate that it would be in the best interests of a student to pursue graduate study at the Institute.

Bi Admission

Applicants are expected to meet the following minimal requirements: mathematics through calculus, general physics, organic chemistry, physical chemistry (or the equivalent), and elementary biology. Students with deficient preparation in one or more of these categories may be admitted but required to remedy their deficiencies in the first years of graduate training, with no graduate credit being granted for such remedial study. This will usually involve taking courses in the categories in which the student has deficiencies. In certain instances, however, deficiencies may be corrected by examinations following independent or supervised study apart from formal courses. Furthermore, the program in biology is diverse, and in particular fields such as psychobiology and experimental psychology, or in interdisciplinary programs, other kinds of undergraduate preparation may be substituted for the general requirements listed above.

When feasible, visits to the campus for personal interviews will be arranged before a final decision for admission is made. Graduate Record Examinations (verbal, quantitative, and an advanced test in any science) are required of applicants for graduate admission intending to major in biology. Applicants are encouraged to take these examinations and request that the scores be transmitted to Caltech, in November or earlier, to ensure unhurried consideration of their applications.

Bi Master's Degree

The biology option does not admit students for work toward the M.S. degree. In special circumstances the M.S. degree may be awarded, provided Institute requirements are met. In general, the degree is not conferred until the end of the second year of residence. The degree does not designate any of the disciplines of the division, but is an M.S. in biology. The 135 units required by the Institute must include any two courses of a three-term series Bi 250 abc and Bi 252.

Bi Degree of Doctor of Philosophy

Major Subjects of Specialization

A student may pursue major work leading to the doctoral degree in any of the following subjects: biophysics, cellular biology, devel-

omental biology, genetics, immunology, microbiology, molecular biology and biochemistry, and systems biology. At graduation, a student may choose whether the degree is to be awarded in biology or in the selected major subject. Students who choose to work in Neurobiology may also qualify for a Ph.D. in Biology but are encouraged to enroll in the Neurobiology option.

Initial Advisory Committee

At the start of the first year of study, incoming students meet with the option representative or faculty member(s) specified by the option representative. The purpose of this meeting is to assist the student in organizing laboratory rotations, and to discuss what additional course work is desirable in light of the student's past record.

Rotations

The major initial responsibility of each student is to explore the various research possibilities available at Caltech before settling into a laboratory for their thesis research. Students are free to rotate in any laboratory at Caltech, not just those in the Division of Biology and Biological Engineering. First-year students should carry out a minimum of two laboratory rotations; three rotations are recommended. It is generally expected that rotations will last a full academic quarter; however, exceptions can be granted with the advance permission of the professor. Choice of laboratory should be made by the end of June of the first year except in extraordinary circumstances. Any exception should be discussed with the option representative.

Formal Classes

During the first year of graduate studies, students are required to take Responsible Conduct of Research (Bi 252), Reading, Writing, Reviewing, Experimental Design and Reproducibility (Bi 253), as well as any two courses of a three-term series (Bi 250 abc) that covers the breadth of fields represented in biology at Caltech. During each year that they are matriculated in the Ph.D. program, students are required to take Bi 251 abc (Biolunch). Students will be required to present their thesis research in Biolunch during their second and fourth years of study.

In addition to these fixed requirements, during their time at Caltech all students must take one additional 200-series or upper-division 100-series course offered by the Division of Biology and Biological Engineering. Students may fulfill this requirement by taking three terms of Bi 250 abc.

Teaching

All students are to serve as teaching assistants for one quarter per year they are in residence, up through the third year.

Admission to Candidacy

The qualifying exam process that a student must complete to be admitted to candidacy is divided into two parts—an oral defense of the proposed thesis research and a written test of competency in the student's chosen area of research.

The Oral Exam

During winter quarter of the second year, a student is to set up a thesis proposal examining committee and prepare a proposal focused on the research project that they expect to pursue for their thesis research. The proposal is defended by the student in an oral presentation in front of the thesis proposal examining committee by the end of June. (Although it is anticipated that this exam will be completed by June of the second year, it can be delayed until August of the third year if the option representative agrees.) The examining committee comprises four faculty members, at least three of whom should hold full or joint professorial appointments in the Division of Biology and Biological Engineering. One of the members of the committee is appointed as chair. The chair of the thesis examining committee must be a Caltech faculty member other than the student's adviser. The adviser can, but need not be, a member of the examining committee. The members of the thesis proposal examining committee must certify passage of this exam. In the event that there is inadequate evidence of the capacity to do research, the student may be allowed to petition to re-take the oral exam at a later time. However, in cases where the committee deems it unlikely that the student will be able to pass a subsequent attempt, the student may be advised to leave the program. In any event, a student cannot remain in the program beyond August of the third year without having successfully completed the requirements for admission to candidacy, except in extraordinary circumstances and with the approval of the option representative and the Dean of Graduate Studies.

The Written Exam

The written qualifying examination is taken in June of the student's second year in the division. Each student chooses one of the following subjects as a major: cellular and molecular neurobiology; developmental biology; genetics; immunology; molecular biology, biochemistry, and cell biology; or systems neurobiology. The exam chair for that major designs a program of study that culminates in the written exam. M.D./Ph.D. students are not required to take the written test of competency unless their adviser specifies that this is required.

Once a student has successfully completed the oral exam and written exam, he or she can apply to be admitted to candidacy. According to Institute regulations, this application process must be completed by the end of the third year of graduate study.

Thesis Advisory Committee Meetings

Once a student has been formally admitted to candidacy, he or she is to pick a Thesis Advisory Committee (TAC). This committee is often the same as the thesis proposal exam committee, but that need not be the case. The thesis adviser must be a member of the TAC. The TAC typically has five members. At least three must be professorial faculty who hold a full or joint appointment in the Division of Biology and Biological Engineering, and at least four must be Institute professorial faculty. It is expected that students who have been admitted to candidacy will meet with the TAC once a year for the remainder of their time at Caltech. Students who fail to meet with their TAC in any one year may be deemed to not be maintaining satisfactory progress toward the Ph.D. degree and will be prevented from registering for the subsequent academic year.

Maintaining Satisfactory Progress

It is the policy of the biology option that a graduate student who is making satisfactory progress toward a Ph.D. degree can expect to continue as a registered student with full financial support. To be deemed as making satisfactory progress, a student is expected to fulfill the expectations listed below. In the event that satisfactory progress is not being made, a student can petition to receive the M.S. degree, for which they must have successfully completed one full year of graduate study.

Requirements for satisfactory progress include:

- Completion of the first-year course requirements during the first year.
- Joining a laboratory in which a student will perform thesis research before the end of the first year in residence.
- Passing the oral and written parts of the qualifying examination and completing admission to candidacy before the start of the year.
- Holding a Thesis Advisory Committee meeting in each subsequent year of studies, and having the thesis committee verify that satisfactory progress is being made.
- Serving as a teaching assistant for one quarter of each academic year spent in residence through third year.
- Completing Ph.D. studies by the end of the sixth year.

In the event that the student, option representative, and adviser are in agreement, it is possible to make exceptions to the above guidelines and remain in good standing. Extension of thesis work beyond twenty-four terms requires that the student petition the Dean of Graduate Studies for permission to register. Extensions beyond the seventh year will be allowed only in unusual circumstances. Once a student has passed admission to candidacy, the responsibility for assessing satisfactory progress lies largely with the student's Thesis Advisory Committee. If a majority of the com-

mittee deems that a student is not making satisfactory progress, the student is at risk of being removed from the program at any time at the discretion of the option representative.

Examination Committee

Requirements for the Ph.D. thesis and examination are determined by the Ph.D. examination committee that is appointed by the Dean of Graduate Studies for each degree candidate. This committee is usually the same as the Thesis Advisory Committee, but this need not be the case. The composition of the committee must be approved by the option representative. The committee usually has five members. At least three must be professorial faculty who hold a full or joint appointment in the Division of Biology and Biological Engineering, and at least four must be Institute professorial faculty.

Thesis and Final Examination

The thesis and associated publications are expected to demonstrate that the student has learned how to conceive, plan, and execute experimental and/or theoretical work that reveals new biological information. In addition, it must reveal a deep, broad, and rigorous understanding of the area of research to which the thesis is relevant.

Two weeks after copies of the thesis are provided to the examining committee, chairman, and option representative, the candidate collects the copies and comments for correction. At this time, the date for the final examination is set at the discretion of the major professor and the division chair. The final oral examination covers principally the work of the thesis, and according to Institute regulations must be held at least two weeks before the degree is conferred. Two copies of the thesis are required of the graduate for the Institute library.

Caltech-Kaiser Permanente School of Medicine MD/PhD Program

There is a dual-degree program between Caltech and the Kaiser Permanente School of Medicine (KPSOM) for the granting of the M.D./Ph.D. degree. Students receive their medical training at KPSOM, and perform their Ph.D. work with any member of the Caltech faculty.

Admission to this dual-degree program is made through the KPSOM M.D./Ph.D. process. The M.D. degree is awarded by KPSOM, and the Ph.D. is awarded by Caltech.

The dual-degree program is directed by Dr. Jose M. Barral, M.D., Ph.D. at KPSOM and Professor Mark Davis at Caltech. For more information, see <https://medschool.kp.org/education/curriculum#dual-degrees>.

Caltech-UCLA Medical Scientist Training Program (MSTP)

A joint program between Caltech and the UCLA Medical School

has been established for the granting of the M.D./Ph.D. degree. Students do their preclinical and clinical work at UCLA, and their Ph.D. work with any member of the Caltech faculty, including the biology, chemistry, and engineering and applied science divisions.

Admission to this joint program is made through the usual UCLA MSTP process, checking a box indicating interest in the Caltech option. Students will be accepted into the joint program, funds permitting. The M.D. degree would be from UCLA and the Ph.D. would be awarded by Caltech.

The current directors of the UCLA MSTP are Dr. Carlos Portera-Cailliau and Dr. Siavash Kurdistani, and Caltech professor David Chan is the associate director. For more information, see mstp.healthsciences.ucla.edu.

Caltech-USC MD/PhD Program

A joint program between Caltech and the USC (Keck) Medical School has been established for the granting of the M.D./Ph.D. degree. Students do their preclinical and clinical work at USC, and their Ph.D. work with any member of the Caltech faculty.

Admission to this joint program is made through the usual USC process, checking a box indicating interest in the Caltech option. Students will be accepted into the joint program, funds permitting. The M.D. degree would be from USC and the Ph.D. would be awarded by Caltech.

The current co-directors of the USC M.D./Ph.D. program are Drs. Mark Davis and David Hinton. The director for Caltech is Professor Mark Davis. For more information, see <http://keck.usc.edu/md-Ph.D.-program/>.

Bi Subject Minor

A student majoring in any non-biology option of the Institute may, with the approval of the Division of Biology and Biological Engineering, elect a subject minor in any of the subjects listed above under major subjects of specialization. Requirements for such a minor are determined by the faculty committee designated for each subject. A minor program in biology is also available to students of other divisions. Such a program shall consist of 45 units of upper division course work in the Division of Biology and Biological Engineering, with each course passed with a grade of C or better. Approval of each program must be obtained from the biology graduate option representative. A student majoring in another division who elects a subject minor in biology may, if desired, arrange to have the minor designated as biology, rather than with the name of the specific minor subject.

CHEMICAL ENGINEERING (ChE)

Aims and Scope of the Graduate Programs

The general objective of the graduate work in chemical engineering is to produce individuals who are exceptionally well trained to apply mathematics, the physical, chemical, and biological sciences, and engineering to the understanding of systems involving chemical reactions, transport phenomena, and materials/energy transformations, and to the development of new processes and materials. The program also strives to develop in each student self-reliance, creativity, professional ethics, and an appreciation of the societal impact of chemical engineering and the importance of continuing intellectual growth.

ChE Admission

It is expected that each applicant for graduate study in chemical engineering will have studied mathematics, physics, chemistry, biology, and chemical engineering to the extent that these subjects are covered in the required undergraduate courses at Caltech. In case the applicant's training is not equivalent, admission may be granted but the option may prescribe additional work in these subjects before recommending him or her as a candidate for a degree.

ChE Master's Degree

Although there is no formal M.S. program in ChE, in the course of their Ph.D. program students may apply for an M.S. degree by submitting an approved thesis and meeting all the other institute requirements for the M.S. program. The thesis must be approved by both the student's adviser and Option Representative.

Course Requirements

At least 135 units of coursework must be completed in order to satisfy the Institute requirements. These units must include ChE 151ab, ChE 152, ChE/Ch 165, 18 additional units of advanced courses in chemical engineering, 27 units of science or engineering electives, and 18 units of general electives. With advanced permission from the Option Representative, general electives may include courses in the humanities and social sciences. A student must maintain a GPA of ≥ 2.0 to qualify for an M.S. degree. Finally, the M.S. requirements include at least 27 units of research, ChE 280, which represents two terms of research under the supervision of a chemical engineering faculty member.

Research Report

At least three weeks before the degree is to be conferred, a research report on the work performed under ChE 280 must be submitted to both the student's adviser and the Option Representative.

ChE Degree of Doctor of Philosophy

1. Coursework

- a. *Initial Consultation:* Upon arrival at Caltech, the ChE Ph.D. students will meet with the ChE Option Representative to discuss the program, adviser selection, and expectations for the first and second terms. During these two terms, students are expected to take a normal load of three courses per term plus 9 units of research (ChE 280) to cover the rotation (see below). The courses during the first term include one each in advanced Kinetics (ChE 152) and Thermodynamics (ChE 165), and a third course in an area of need or an area that lines up with the research interests of the student. The courses during the second term include one each in advanced Transport (ChE 151 a) and Statistical Thermodynamics (ChE 164) and a third course as above. The third course taken during the first and second terms must be at least 9 units and graded. The entire first year of study will also be discussed.
- b. *Course Requirements:* During the first year, Ph.D. students are required to take the five core courses: ChE 151ab, ChE 152, ChE 164, ChE 165, plus one additional ChE course from the following list: ChE 112, 115, Ch/ChE 140, 147, 148, 155, ChE/ESE 157, 158, 159, ChE/BE 163, 174. The core courses must be graded and a minimum grade of B- is required in each one. There is also a minimum GPA requirement of 2.5 each term of all courses taken. Failure to meet these grade and GPA requirements places the student in a state of deficiency, which may lead to termination of the program if not corrected promptly.
- c. *Subject Minor or External Coursework:* Each student is required to complete either a subject minor or a general program of courses outside chemical engineering. The general program of courses consists of at least 54 units. A maximum of 27 units from the following list of doubly-listed courses can be used by graduate students as part of the 54 unit requirement: ESE/ChE 158; ChE/Ch 140, 147, 148, 155, ESE/Ge/Ch 171. A course in the ACM 100ab sequence will be credited 9 units instead of the nominal 12 units as listed in the catalog. Courses in the Humanities, Arts, and Linguistics are explicitly excluded from the general program. The requirements for a subject minor in other options may be found in the current Caltech Catalog. The general program of courses must be submitted and approved by the Option Representative after the candidacy exam. All courses chosen must be at the graduate level and should constitute an integrated program of study rather than a randomly chosen

collection of courses outside chemical engineering. A grade of C or better is required in any of these courses to remain qualified for the Ph.D. program.

2. Research Adviser

The choice of a research adviser is perhaps the most important decision a graduate student makes during the first year of graduate study. This decision must be made before the end of the second term of the first year, and so it is reasonable to devote significant thought and effort to this task before then.

In the first two weeks of the Fall quarter, all faculty will present overviews of their research program during informal evening sessions. All first-year students must attend all of these sessions. Following these presentations, the students are expected to meet individually with at least two faculty members to discuss proposed research projects and the possibility of doing a rotation in that faculty member's group during the first or second terms. All students must formally join a group by the end of the second term.

3. Rotations

Rotations serve to acquaint the student with a group's research area and style. Two rotations are required, one each during the first and second terms. During a rotation, the student must participate in research activities in the chosen group for at least nine hours per week under the tutelage of a faculty or senior group member. At the end of a rotation, the student must produce a research report and give a group presentation. Afterwards, a rotation completion form must be signed by the rotation adviser and returned to the ChE Option Representative. At the same time, the student and the faculty member must determine whether the "match" of research interests and personalities is good. In the instance of a positive outcome, the student may remain in the same group for a second rotation. Otherwise, the student should proceed to do a second rotation in another group with the same requirements as above. Certain funding agencies (e.g. NIH) require a second rotation in a different group. In that case, the student will be asked to do so, even if she/he desired to remain in a particular group; the student may return to join the first group after completion of the second rotation. All students must find advisers and formally join a group by the end of the second term. Failure to do so terminates the Ph.D. program at Caltech and the student will be asked to leave.

4. Candidacy Exam

All students are required to pass the candidacy examination, ideally before the official start of the second year, or at the latest by

October 15 of the second year. This oral exam is administered by a Candidacy Committee and consists of two parts:

- a. A presentation by the student based on the contents of a research progress report.
- b. A background questions part broadly related to the research problem presented.

The research progress report must be submitted to the Candidacy Committee members and the ChE Option Representative by August 31st of the first year in residence. The report should expound on the research pursued by the student and is expected to exhibit originality and a professional quality of exposition. It should outline the research problem, the proposed approach, the expected contributions in the general problem area, and the progress of the student at the time of writing. It should also provide clear evidence of the student's understanding of the research topic, the underlying science and technology related to that research, and the student's mastering of the relevant techniques and methodology necessary to pursue the proposed research.

The Candidacy Committee should consist of no fewer than four voting members of the Caltech faculty, with at least three being Chemical Engineering faculty. To ensure the impartiality of the committee, the Chairperson and at least one more of the committee members must have no direct Advisory relationship with the candidate. The choice of the oral exam committee will be made by the student and his/her research adviser and must be approved by the ChE Option Representative. It is the responsibility of the student to obtain approval from each proposed committee member for the date and time of the oral exam. The list of the recommended committee members must be submitted to the Option Representative at the same time as the research progress report.

The second component of the oral exam consists of chemical engineering background questions relating broadly to the student's research topic. The Chairperson of the Candidacy Committee shall be responsible for ensuring that the questions are at an appropriate level, consistent with that of undergraduates at Caltech. For example, if the Ph.D. focus is on heterogeneous catalysis, the student must be able to answer questions on basics such as: surface reaction mechanisms, diffusion/reaction in porous media, and multi-component gas-phase transport, etc. Similar considerations apply to Ph.D. projects related to fluid mechanics, thermodynamics, basic biology, physics, chemistry, etc. The advanced courses taken during the first year should help you prepare well for this part of the exam. Serious gaps in the understanding of classical chemical engineering concepts, approaches, and methodologies applicable to your research may lead to failing the exam even if research progress is deemed adequate. Furthermore, for interdisciplinary projects going beyond classical Chemical Engineering, the student

will be expected to demonstrate good understanding of the fundamentals in other areas directly relevant to their project.

The candidacy exam may have three outcomes: Pass, Conditional Pass, or Fail. Passing the candidacy exam admits the student to Candidacy for the Degree of Doctor of Philosophy. Failing the candidacy exam terminates the student's Ph.D. program at Caltech. When course requirements are met, the student may be awarded an M.S. degree at the recommendation of the Candidacy Committee. Conditional Pass is a special outcome granted only when the student has clearly passed the background questions component, but the committee deems that more is needed on the research front. In this case, the committee chair will put in writing what is required and the time frame to meet those requirements. Under no circumstances is this time to exceed one term. Meeting the stipulated requirements must be reflected in a revised candidacy report, which must be submitted to and approved by the Candidacy Committee by the set deadline. It is at the discretion of the committee to request a re-examination. In any case, a Pass or Fail decision must be reached at the latest by December 15th of the second year in residence. This is a hard deadline for both the student and the committee. If there is no communication to the ChE Option Representative by December 15th, a Fail decision will be entered automatically.

5. Thesis Review Committee

After the student passes the candidacy exam, the Candidacy Committee becomes the "de-facto" Thesis Review Committee, which will be responsible for reviewing the student's progress. The committee must be convened (as a group) during the third year of residency, and every year thereafter to review progress, suggest improvements in research, or resolve any issues that could potentially delay graduation beyond the fifth year of residency. It is the responsibility of the student to organize the annual meetings of the Thesis Review Committee, which may be convened at any time during the year but at least three months before registration for the next academic year is due. Subsequent registration beyond the fourth year is subject to written approval by the Thesis Review Committee and the ChE Option Representative. In order to expedite the review, the student should submit a two- or three-page concise outline of progress and of proposed future research to each member of his/her committee before the annual review meeting.

6. Final Thesis and Oral Defense

As a final step in the Ph.D. program, the student is required to submit a satisfactory thesis, present a ChE seminar (open to the general public), and pass a final oral examination.

Procedures for Seminar, Exam, and Committee Selection:

At least three weeks prior to the exam date, the ChE Graduate Records Secretary must be given the title of the seminar, date, time and location. Both the seminar and exam should be scheduled on the same day, with the exam immediately following the seminar. The committee members will be determined by the student and their research adviser, and must be approved by the ChE Option Representative and the Dean of Graduate Studies. The examining committee must include at least four members, of which at least three are voting members of the Caltech faculty and at least two are ChE faculty; one member of the committee may be from off-campus with prior approval of the ChE Option Representative.

7. Graduate Teaching Assignment Duties

All Ph.D. students are required to perform a minimum of 24 term-hours of GTA duties within the ChE Department during their studies. The GTA duties will normally be assigned after the first year in residence. Most students find the teaching assistantship a valuable experience for their future careers. Teaching assistantships outside ChE are permitted but the hours do not count toward the 24-hour TA requirement.

Additional Information

Additional information about graduate study requirements and procedures is provided in the chemical engineering graduate studies guide, distributed annually to first-year chemical engineering graduate students.

CHEMISTRY (Ch)

Aims and Scope of the Graduate Program

The Caltech Chemistry option offers a program of graduate study leading to the Ph.D. degree, with the goal of preparing students for a lifetime of independent research and scientific leadership in the chemical sciences, through careers in academia, industry or government. Modern chemistry strives to achieve a molecular-level understanding of the natural world and thus forms the basis for much of modern science, including biology, medicine, materials, nanotechnology, energy and environment. The program of study, while anchored in the traditional areas of organic chemistry, inorganic chemistry, chemical biology, biochemistry and biophysics, chemical physics and theoretical chemistry, is flexible and highly interdisciplinary.

The graduate program in chemistry emphasizes research. This emphasis reflects the Institute's traditional leadership in chemical research and the conviction that has permeated the Division of

Chemistry and Chemical Engineering from its founding, that participation in original research is the best way to awaken, develop, and give direction to creativity.

The program is designed to encourage students to begin their research early in their first year. Students can elect to do research that crosses the boundaries of traditionally separate areas of chemistry, for in this relatively compact division, they are encouraged to go where their scientific curiosity drives them. A thesis that involves more than one adviser is not uncommon, and interdisciplinary programs with biology, physics, geology, chemical engineering, and environmental science and engineering science are open and encouraged.

An extensive program of seminars will enable students to hear of and discuss notable work in chemical physics, organic chemistry, inorganic chemistry and electrochemistry, organometallic chemistry, and biochemistry and molecular biophysics. Graduate students are also encouraged to attend seminars in other divisions.

Ch Learning Outcomes

Students upon whom are conferred the Ph.D. degree have provided evidence of independent scholarship and scientific creativity through the performance of original research, which is described in their doctoral thesis and defended orally. Students must also demonstrate an ability to conceive new research directions by preparing and defending a set of written research propositions.

Ch Course Program

A student is required to complete at least five courses, each being nine units or more, in science or engineering. At least one course must be in a field substantially outside the research area of the student. Courses may be either inside or outside the chemistry option, must be numbered 100 or greater, and must be taken on a letter-grade basis with a grade of B or above. The student should discuss, with his or her adviser, which courses best serve his or her individual needs. The program of courses must be approved by the research adviser and by the Chemistry Graduate Study Committee.

Ch Master's Degree

Students are not ordinarily admitted to graduate work leading to an M.S. degree. Under special circumstances, and with prior approval of the Graduate Study Committee, a master's degree can be obtained. All master's programs for the degree in chemistry must include at least 45 units of chemical research and must satisfy the Course Program described above. The remaining electives may be satisfied by advanced work in any area of mathematics, science or engineering, or by chemical research. A satisfactory thesis describing this research, including a one-page digest or summary of the main results obtained, must be submitted to the divisional graduate

studies office at least 10 days before the degree is to be conferred. In addition, the fulfillment of the thesis requirement must be signed off by a designated faculty member on the M.S. candidacy form and a final copy of the thesis submitted to the Graduate Office no later than two weeks before the degree is to be conferred. The copies of the thesis should be prepared according to the directions formulated by the Dean of Graduate Studies and should be accompanied by a statement of approval of the thesis, signed by the adviser directing the research and by the chair of the Chemistry Graduate Study Committee.

Ch Degree of Doctor of Philosophy

Selecting a Research Project

Soon after a new graduate student arrives in the laboratories, he or she attends a series of orientation seminars that introduce students to the active research interests of the faculty. Students then meet with each of five or more faculty whose fields attract them, to discuss in detail potential research problems. They eventually settle upon the outlines of a research problem that interests them and select a specific research adviser (or set of co-advisers). Neither students nor faculty can make a commitment to an adviser-advisee relationship prior to the end of the first month of the fall term. Students typically begin research during their first academic year.

Candidacy

To be recommended for candidacy for the doctor's degree in chemistry, in addition to demonstrating an understanding and knowledge of the fundamentals of chemistry, a student must give satisfactory evidence of proficiency at a high level in the primary field of interest, as approved by the division. This is accomplished by an oral candidacy examination, which must be held during or before the fifth term of graduate residence (excluding summer terms). The candidacy committee shall consist of the thesis adviser(s) and two additional faculty members; at least two of the three members must be chemistry faculty. The committee should be considered as a resource for the student for the remainder of his or her studies. At the candidacy examination, a student is asked to demonstrate scientific and professional competence and promise by discussing a research report and propositions as described below.

The research report should describe progress and accomplishments to date and plans for future research. Two original research propositions, or brief scientific theses, must accompany the report, and at least one must be well removed from the student's field of research. These propositions should reflect his or her breadth of familiarity with the literature, originality, and ability to pose and analyze suitable scientific research problems. The research report and propositions must be in the hands of the examining committee as a bound, hard-copy document one week before the examination.

The result of the candidacy examination may be either (a) pass, (b) fail, or (c) conditional. Conditional status is granted when the committee decides that deficiencies in a student's research report, propositions, or overall progress can be remedied in a specific and relatively brief period of time. In order to change conditional to pass status, the student must correct the indicated deficiencies or in some cases schedule a new examination the following term. He or she must be admitted to candidacy at least three terms before the final oral examination. A student cannot continue graduate work in chemistry (nor can financial assistance be continued) past the end of the sixth term of residence without being admitted to candidacy, except by petitioning the division for special permission. This permission, to be requested by a petition submitted to the Graduate Study Committee stating a proposed timetable for correction of deficiencies, must be submitted before registration for each subsequent term (including the summer following the sixth term of residence) until admission to candidacy is achieved.

Graduate Teaching Assignment Duties

All Ph.D. students are required to perform a minimum of one 9 term-hour GTA within the chemistry option before the completion of the fourth year of study. Most students find the teaching assistantship a valuable experience for their future careers.

Language Requirement

There is no formal foreign language requirement for the Ph.D. in chemistry. However, the division believes strongly in the professional importance to chemists of knowledge of foreign languages and encourages their study prior to graduate work or while in graduate school.

Ph.D. Thesis Committee

In the third year, the student in consultation with their adviser will form their Ph.D. thesis committee. This committee will comprise at least four faculty members and will generally consist of the original candidacy committee plus an additional member of the faculty; at least three of the members must be from the chemistry option. The student must meet with their committee annually, beginning in the third year. At these informal meetings, the student will update the committee on the status of their research.

Typically, a student will provide an updated CV, a short research summary (2-3 pages), and a brief outline of plans for the coming year.

Fourth Year Progress Meeting

Before the thirteenth academic term of graduate residence (excluding summer terms), the student will be expected to demonstrate satisfactory progress in the course of thesis research. To this end, an informal meeting with the Ph.D. thesis committee will be held. Typically, a student provides an updated CV, a short research summary (2-3 pages), a thesis outline with %-completed for each chapter, and a timeline for completion of the degree. At the meeting, the student will likely present an oral summary of research completed to date as well as an outline of future research plans. Following the discussion, an appropriate timetable for completion of the degree requirements will be discussed and agreed upon. It is also common to discuss plans for post-Caltech at the meeting.

Length of Graduate Residence

Any graduate student who anticipates a need to register for a twenty-fourth academic term must hold a meeting of his or her thesis committee and present the institute-required petition for permission to register that includes a plan of action for the period of the requested registration and a specific date for the completion of the degree requirements. This petition must be approved by the Thesis Committee, by the chair of the Chemistry Graduate Study Committee and, in cases where financial support is an issue, by the executive officer or division chair, before it is forwarded to the Dean of Graduate Studies. Financial support of graduate students who are required to petition to register will not normally be provided through teaching assistantships. Failure to complete the degree requirements by the date specified in the petition would require the entire approval process to be repeated. This process must be repeated for every subsequent year.

Thesis and Final Examination

The final examination will consist in part of the oral presentation and defense of a brief résumé of the student's research and in part of the defense of a set of propositions he or she prepares. Three original research propositions are required. No more than one of these may be a carryover from the candidacy examination, and at least one must be well removed from the field of research. Each proposition shall be stated explicitly and the argument presented in writing with adequate documentation. The propositions should display originality, breadth of interest, and soundness of training; a student will be judged on the selection and formulation of the propositions as well as on the defense of them. Formulating a set of propositions should begin early in the course of graduate study.

To emphasize the importance of these propositions, there will be a separate examination on the three propositions by the Ph.D.

thesis committee. This examination on the propositions is normally taken after the thesis research progress meeting, but not less than 10 weeks in advance of the final doctoral examination. A copy of the propositions, along with suitable abstracts, must be submitted to the examining committee not less than two weeks before the propositions examination. These propositions must be acceptable to the committee before the final doctoral examination can be scheduled.

A copy of the thesis must be submitted to each member of the thesis committee not less than two weeks before the final doctoral examination. A copy of the thesis should also be submitted to the Graduate Office for proofreading three weeks prior to the final doctoral examination. Two final copies (one on Permalife paper) are to be submitted to the Graduate Office.

Ch Subject Minor

Graduate students in other options taking chemistry as a subject minor will be assigned a faculty adviser in chemistry by the Chemistry Graduate Study Committee. In consultation with this adviser, the student will work out an integrated program of courses, including at least 45 units of formal course work at the 100 level or above. This program must be approved by the Chemistry Graduate Study Committee, and a grade point average of 3.0 in the approved program will be required.

CIVIL ENGINEERING (CE)

Aims and Scope of the Graduate Program

Civil Engineering (CE) research and study are offered through the Department of Mechanical and Civil Engineering (MCE). The degrees of Doctor of Philosophy (Ph.D.) and Master of Science (M.S.) are offered. In general, students who intend to work full-time toward the Ph.D. degree as a final degree objective are admitted to the civil engineering graduate program. The M.S. degree is typically only awarded to students who pursue the Ph.D. degree in civil engineering at Caltech and who do not already have an M.S. degree in civil engineering.

The aim of the graduate program in civil engineering at Caltech is to prepare students for research and professional practice in an era of rapidly advancing interdisciplinary technology. The program combines individual depth of experience and competence in a particular chosen major specialty, with a strong background in the basic and engineering sciences. It strives to develop professional independence, creativity, leadership, and the capacity for continuing professional and intellectual growth.

CE Preparation for the Graduate Program

Entering graduate students are expected to have a thorough back-

ground in undergraduate mathematics, physics, and engineering. While a strong undergraduate program in civil engineering should provide a suitable preparation, students who have not specialized in civil engineering as undergraduates may also be admitted for graduate study. For example, an outstanding four-year undergraduate program in mathematics and sciences may provide a suitable background as well. The qualifications of each applicant will be considered individually, and, after being enrolled, the student will arrange his or her program in consultation with a member of the faculty.

CE Master's Degree

The degree of Master of Science in civil engineering is only awarded to students who do not already have an M.S. degree in civil engineering. The degree will be awarded upon request by students who have fulfilled the requirements. Only in exceptional cases is there admission to the M.S. program as the final degree objective.

A minimum of 138 units of courses numbered 100 or above, which meet the required master's program listed below, must be passed with a grade of at least C for completion of the master's degree in civil engineering. All units must be taken for grades, except for courses offered only on a pass/fail basis. The M.S. degree in civil engineering is typically completed within the first two years of residency at Caltech.

Each student's program must be approved by the adviser and option representative in mechanical and civil engineering before registering for the course.

Required Master's Program

- a) Graduate civil engineering core (45 units). These units should provide a solid base for the student's engineering interest. The courses should be selected from the Core CE subjects listed under the of the Degree of Doctor of Philosophy Description and Requirements section.
- b) Mathematics, engineering, and research electives (63 units). Students who have not taken the equivalent of ACM 100 ab are required to take ACM 100 ab for 24 units. Research can be included up to a maximum of 27 units.
- c) Free electives (27 units). Any course with a number of 100 or greater may be selected, except that research units may not be included.
- d) Graduate Engineering Seminar, AM/CE/ME 150 abc (3 units).

CE Degree of Doctor of Philosophy

The Ph.D. degree in civil engineering is focused on research. Study and research programs for the Ph.D. degree are individually planned to fit the interests and background of the student. A

comprehensive research project resulting in an original contribution to the field which is documented by a thesis is required. Institute requirements for the Ph.D. degree are described in the section on degree requirements. A minimum of three academic years in residence as a graduate student are required by the Institute, and two or more additional years are usually needed for preparation of the thesis.

Advising and Thesis Supervision

An interim adviser is appointed for each student upon admission to a graduate degree in civil engineering. The interim adviser will serve as the primary mentor until the student finds a research adviser. It is the responsibility of the student to find an academic and research adviser within three terms of graduate residence at Caltech. In consultation with the adviser, the student must form a Ph.D. Thesis Advisory Committee within four terms of graduate residence at Caltech. This committee shall consist of at least three members of the Caltech professorial faculty, with at least two members from the faculty in mechanical and civil engineering. The committee shall meet as requested by the student. Further, the committee shall meet annually to review progress and to approve the registration of the student beyond the fifth year of graduate residence at Caltech.

The adviser and the Thesis Advisory Committee provide the majority of mentoring to the student. In addition, the option representative and other members of the faculty are always available to provide advice and mentoring on any aspect of research, progress toward the Ph.D., future careers, and other aspects of graduate school.

Admission to Candidacy

To be recommended for candidacy for the Ph.D. degree in civil engineering, the student must, in addition to meeting the general Institute requirements, do the following:

- Obtain the agreement of a professorial faculty member to serve as his or her academic and research adviser before the end of the third term of graduate residence at Caltech. In consultation with the adviser, the student must form a Ph.D. Thesis Advisory Committee before the end of the fourth term. This committee shall consist of at least three members of the Caltech professorial faculty, with at least two members from the faculty in mechanical and civil engineering.
- Pass both subject and research components of the oral candidacy examination before the end of the eighth term of graduate academic residence at Caltech. If the student has chosen a subject minor, an examination on the subject of that program may be included at the request of the discipline offering the subject minor.

- Complete a minimum of 195 units of courses numbered 101 or above, that meet the required Ph.D. program listed below. All units must be taken for grades and passed with a grade of at least a C, except for courses offered only on a pass/fail basis. The course work towards the Ph.D. degree in civil engineering is typically completed within the first three years of residency at Caltech.

Required Ph.D. Program

Civil Engineering Core Subjects (45 units): Course work in core subjects selected from the list below; pass with a grade of at least C: Ae/APh/CE/ME 101abc, Ae/AM/CE/ME 102abc, AM/CE 151, Ae/Ge/ME 160ab, ME/CE 163, Ae/CE165ab, ME/CE/Ge 174, CE 181ab, Ae/AM/MS/ME 213ab, Ae/AM/CE/ME 214ab, Ae 220, Ae/CE 221, Ae/AM/ME 223, AM/CE/ ME 252, ME/Ge/Ae 266ab.

- Electives or Minor* (63 units): Additional engineering or science courses with course number 101 or above. Pass with a grade of at least C, courses that are approved by the thesis advisory committee. These courses are intended to provide further depth and incorporate breadth. These units can be used to satisfy a minor requirement in another option.
- Advanced mathematics or applied mathematics* (27 units): Pass with a grade of at least C, chosen in consultation with adviser from the following list: ACM 101 or higher, CDS 232, Ma 108 or higher, Ph 129. The requirement in mathematics is in addition to the requirements above.
- Graduate engineering seminar* (6 units): six terms of AM/CE/ME 150 abc, within twelve terms or 3 years in residence at Caltech.
- Research* (54 units). Successfully complete at least 54 units of research and demonstrate satisfactory research progress.

Registration Beyond the Sixth Year of Graduate Residence

The annual approval of the Ph.D. dissertation supervision committee is necessary for registration beyond the twenty-fourth academic term of graduate residence at Caltech.

Thesis and Final Examination

The thesis examination will be given after the thesis has been formally completed. This examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in the specialized field of research. The format of the examination can be chosen from the following two options, by the student, in consultation with their research adviser: (i) a public seminar presented by the candidate, with an open question period, followed by a private examination by the examining committee or (ii) a private presentation to the examining committee followed by the examination, with a public seminar on

another date. The examining committee shall consist of a minimum of four voting members, three of whom must be Caltech faculty; two members must be from MCE. The thesis defense committee shall be chaired by a committee member who is an MCE Caltech professorial faculty member and not the student's adviser.

CE Subject Minor

A student majoring in another branch of engineering or another division of the Institute may, with the approval of the faculty in the department of mechanical and civil engineering and the faculty in his or her major field, elect civil engineering as a subject minor. The program of courses must differ markedly from the major subject of study or research, and must consist of at least 54 units of advanced courses (101 or above) approved by the faculty in mechanical and civil engineering.

COMPUTATION AND NEURAL SYSTEMS (CNS)

CNS Aims and Scope of the Graduate Program

An integrated approach to graduate study combining computation and neural systems is organized jointly by the Division of Biology and Biological Engineering, the Division of Engineering and Applied Science, and the Division of the Humanities and Social Sciences. This curriculum is designed to promote a broad knowledge of aspects of molecular, cellular, and systems biology, cognitive neuroscience, computational biology and computational neuroscience, information and learning theory, emergent or collective systems, and computer science and electrical engineering in conjunction with an appropriate depth of knowledge in the particular field of the thesis research. For more details, see www.cns.caltech.edu.

Admission

Ideal applicants will have a Bachelor of Science degree or equivalent with a strong quantitative background and some facility with computer programming. They will have shown an interest in understanding the brain and/or in autonomous intelligent systems. All applicants are strongly encouraged to submit their Graduate Record Examination (GRE) verbal and quantitative scores.

Advisory Committee and TA Requirement

An advisory committee of three CNS faculty members is constituted for each student by the CNS admissions committee upon admission to the program. The faculty in whose lab the student is staying first chairs this committee. The advisory committee meets with the student when he or she arrives, guides and approves first-year course choices, and answers questions and offers advice about the program and the way of life in CNS. The CNS faculty are available to students during the year for formal and/or informal discussions.

It is expected that each graduate student will serve as a teaching assistant in one or two CNS courses during his or her residency at Caltech as part of the Ph.D. graduation requirement.

CNS Master's Degree

Only students who expect to pursue the Ph.D. degree will be admitted to the option. The master's degree may be awarded in exceptional cases. The awarding of this degree requires fulfilling the Institute requirements for a master's degree, satisfying the option breadth requirements (see following section), the completion of a master's thesis, and receiving from a candidacy examination oral committee a recommendation for awarding the degree.

Laboratory Rotations

Mandatory rotations through research groups (labs) provide a unique opportunity for the student to experience the CNS culture. To broaden the student's knowledge and to provide familiarity with different techniques and ways of thinking or doing research, each student should carry out three 12-week laboratory rotations (one per term) during the first year, and should engage in research. During each rotation, the student is expected to take part in the life and routine of the lab by attending lab meetings, participating in research projects and discussions with members of the lab, and meeting monthly with the faculty of that lab to discuss science.

Course Requirements

Six nine-unit courses are required during the first year: CNS/Bi/Ph/CS/NB 187, either Bi 9 or equivalent, or Bi/CNS/NB/Psy 150, a neurobiology or modeling course, a math course, and two other CNS, Bi, EE, ACM, or Ph courses (for example, a schedule of CNS/Bi/EE/CS/NB 186, CNS/Bi/Ph/CS/NB 187, Bi/CNS/NB/Psy 150, and CS/CNS/EE 156 satisfies this requirement). CNS students are required to take two additional classes: the one-unit survey course CNS 100, and the four-unit course Bi 252. These eight courses must be taken for letter grades. Students are free to take additional classes, and a research adviser may require that a student take a specific, complementary course as a requirement for joining his or her lab.

Candidacy

Four faculty, including the three faculty in whose labs rotations have been done, should be on the student's candidacy exam committee. At the end of the first year, the student is expected to decide on a research group and begin work there. The first summer is thus expected to be spent entirely on research in that lab. To be recommended for candidacy you are required to pass two tests: the general knowledge exam, and the research and candidacy exam. These exams are supervised by the CNS option representative.

The general knowledge exam satisfies the breadth requirement. A list of about 100 questions, grouped by category, is available at www.cns.caltech.edu, providing a clear idea of the scope of knowledge that each student is expected to know well. Students are encouraged to organize working and discussion groups to prepare for this exam; the format and implementation of such a system, however, is left to the students.

This is an oral exam with the four faculty (including the heads of the student's three rotation labs and one other chosen for "breadth," of whom one can be from outside Caltech). It should be scheduled by the student (who contacts the committee members) to take place during the last six weeks of the third term of year one. For the exam, the student must answer questions (from more than one category) taken from the list, which is modified each year. (The exam can be retaken after three months.)

The research and candidacy exam satisfies the depth requirement. During year two, the student is expected to produce a piece of work of a quality sufficient to be presented at a professional meeting. (The objective of this description is to offer a way to calibrate the level of expected research achievement and involvement. Professional acceptance of the abstract or paper is not a requirement for passing candidacy.) This work is presented in an oral exam in spring term of year two, before the same exam committee (if possible) that conducted part one of the exam. The exam focuses exclusively on research (accomplished and/or planned). During year two, the student may take other courses, as needed, but is expected to present a high standard (quality, originality) of research at the time of this second part of the candidacy exam.

Thesis Advisory Committee

Once admitted to candidacy, the student chooses a Thesis Advisory Committee of at least three faculty. This committee serves as a source of advice independent of the Ph.D. adviser throughout the student's tenure. Each year, before the end of June, the student delivers a written progress report, followed by a meeting with the Thesis Advisory Committee.

Thesis Examination Committee

This committee should consist of a minimum of four voting members, three of whom must be Caltech faculty. The final oral examination covers principally the works of the thesis, and according to Institute regulations must be held at least three weeks before the degree is to be conferred.

CNS Subject Minor

Students majoring in other fields may take a subject minor in CNS, provided the program is supervised by a CNS adviser, is approved by the CNS option representative, and consists of 45 units, includ-

ing Bi/CNS/NB/Psy 150, CNS/Bi/Ph/CS/NB 187, Bi 252, and other CNS cross-listed classes. A subject minor is not required for the Ph.D. degree in CNS.

COMPUTATIONAL SCIENCE AND ENGINEERING (CSE)

Aims and Scope of the Minor

Computational science and engineering (CSE) may be pursued as a subject minor by graduate students who are pursuing Ph.D. degrees in any option. The CSE minor is intended to supplement one of Caltech's graduate degrees and is designed for students who wish to broaden their knowledge of CSE beyond their major field of study. The CSE minor is also intended to recognize graduate students' interest in and dedication to CSE as demonstrated by the successful completion of a program of study in the field. Completion of the CSE minor program of study will be recognized on the Ph.D. diploma by the statement, "...and by additional studies constituting a minor in Computational Science and Engineering."

Requirements

To receive the CSE minor, graduate students must fulfill the following requirements.

- 18 units (two terms) from the following list: ACM/EE 106 ab, CMS/ACM/IDS 113, ACM 114 ab, ACM 116, ACM 117, ACM 157, ACM 158, ACM 210 ab, ACM/IDS 216.
- 18 units (two terms) from the following list: CS 115, CS 138 abc, CMS/CS 139 abc, CS 143, CS/IDS 150 ab, CMS/CS/CNS/EE/IDS 155, CS/CNS/EE 156 a, CS 179.
- 9 units (one term) from the list: Ae/AM/CE/ME 214 abc, Ae/AM/ME 232 ab, Ay 199, Ch 121 ab, GE 263, Ph/CS 219 abc.

All courses to be applied toward the CSE minor requirements must be taken on a graded basis, and students must obtain a grade of B or higher in all courses. Courses that are used to satisfy the CSE minor cannot be used to satisfy course requirements in the major options unless absolutely required by the option. Courses taken as part of the CSE minor are counted toward the total number of units required for the completion of the Ph.D. degree.

CSE Minor Administration

The CSE minor is administered by an oversight committee consisting of three faculty members reporting to the chair of the engineering and applied science division. In consultation with their advisers and, if needed, with the CSE Oversight Committee, students formulate a program of approved courses individually tailored to each student's background and needs, with the objective that the student achieve a level of competence in specific subjects relevant

to CSE. Students must petition the CSE Oversight Committee for approval of their program of study. Upon completion of the program of study, the CSE Oversight Committee will verify that the CSE minor requirements have been fulfilled.

COMPUTER SCIENCE (CS)

Aims and Scope of the Graduate Program

Graduate study in computer science within the Computing & Mathematical Sciences department is oriented principally toward Ph.D. research. The Ph.D. program requires a minimum of three academic years of residence; required coursework is generally completed within the first two years. Students must maintain high academic standards during their graduate residence. A student's Ph.D. research must exhibit originality in the formulation, analysis, and solution of a problem that is significant to the field of study. The option representative and executive officers are available to discuss concerns regarding academic progress.

CS Master's Degree

There is no terminal M.S. degree in Computer Science. In exceptional circumstances (typically when a student leaves the Ph.D. program without completing the degree), the option representative may approve the awarding of a M.S. degree, if the course requirements have been met and the student has passed the preliminary examination (both are described below).

CS Degree of Doctor of Philosophy

Course requirements

Students must complete a minimum of 135 units of courses numbered 100 or greater, including research units (CS 280). Students should consult with their adviser to ensure balance in the selected courses.

The coursework must include:

- CMS 290 is required for all first year CS graduate students during each term (fall/winter/spring).
- Advanced courses in computer science. Completion of a minimum of 54 units of CS courses numbered 100 or greater in addition to units earned for reading, research, and independent projects. Up to 24 of the 54 units may be taken from non-CS courses from CMS or ACM, including CMS/ACM/IDS 107, CMS/ACM/IDS 113 and CMS 117, or other courses with approval from the option representative.
- Units outside computer science. Completion of a minimum of 27 units outside computer science. Courses jointly listed with computer science cannot be used to fulfill this requirement.

Preliminary examination

Toward the end of the first year, all incoming students must take a preliminary examination administered by the faculty. Its purpose is to ensure a solid and broad knowledge in computer science, and in the event of a deficiency, to direct the students to necessary courses and reading.

Candidacy

To be recommended for candidacy, a student must have completed the required coursework, have passed the preliminary examination, have entered upon a course of research approved by his or her thesis adviser, and have passed a candidacy oral examination. The candidacy oral examination is administered by a committee that consists of four faculty that is approved by the option representative. The chair of the committee must be a Caltech professorial faculty member distinct from the adviser. The examination ascertains the student's breadth and depth of preparation for research in the chosen area. The candidacy examination should be taken within the first three years of graduate study.

Advising and Thesis Supervision

In order to facilitate close supervision and a highly research-oriented environment, each student is admitted directly to an adviser and research group. A course of study is determined in consultation with the adviser. Occasionally students will be admitted into more than one group. Changes in affiliation may occur with the common consent of the student and the new adviser.

Students meet regularly with their adviser throughout their time at Caltech, and are encouraged to do the same with other members of the faculty.

Thesis and Final Examination

A final oral examination will be scheduled and given after the Ph.D. thesis has been submitted for review to the student's adviser and thesis committee; the latter consists of at least four faculty approved by the option representative. The chair of the committee must be a Caltech professorial faculty member distinct from the adviser. The thesis examination is a defense of the thesis research and a test of the candidate's knowledge in his or her specialized fields.

Subject Minor in Computer Science

A subject minor is not required for the Ph.D. degree in computer science. However, students majoring in other fields may take a subject minor in computer science, provided the program is supervised by a computer science faculty adviser, is approved by the computer science option representative, and consists of 45 units sufficiently removed from the student's major program of study.

COMPUTING AND MATHEMATICAL SCIENCE (CMS)

Aims and Scope of Graduate Program

Algorithmic thinking is emerging as a fundamental tool for all researchers, not just computer scientists. Algorithmic thinking now drives disciplines ranging from statistics and electrical engineering to biology and physics to economics and the social sciences. Computing and Mathematical Sciences (CMS) is an interdisciplinary Ph.D. program that trains students to apply algorithmic thinking to problems across science and engineering. Our research mission is to build the mathematical and algorithmic foundations required to move from data to information to action. Students will study structures and mechanisms that store, process, and communicate information and that make decisions based on this information. These systems may be expressed in silicon and called computers, in lines of code called programs, or in abstract notation called mathematics. They may appear in economics as markets or social networks, as sequences of amino acids in DNA, or in the organic structure of the human brain.

CMS Master's Degree

Only students who expect to pursue the Ph.D. degree will be admitted to the option. The master's degree may be awarded in exceptional cases. The awarding of this degree requires fulfilling the Institute requirements for a master's degree, satisfying the core course requirements, and receiving a recommendation for awarding of the degree from the preliminary exam committee.

CMS Degree of Doctor of Philosophy

Institute requirements for the Ph.D. degree are described in the section on degree requirements. Approximately two years of coursework are required, and two or more years are usually needed for preparation of the dissertation.

CMS Admission to Candidacy

To be recommended for candidacy for the Ph.D. degree in Computing and Mathematical Sciences the student must, in addition to meeting the general Institute requirements, do the following:

Core requirement

Each student will take six core CMS classes, three in applied mathematics (ACM) and three in Computer Science (CS). In both fields, at least two of the three classes will be taken the first year to prepare for the preliminary examination, while the remaining classes will be completed by the end of the student's second year. The core CMS classes are CMS/ACM/IDS 107, CMS/ACM/IDS 113, CMS 117, CMS/CS/IDS 139, CMS/CS/EE/IDS 144, CMS/CS/CNS/IDS 155. These classes must be taken for a grade.

Depth requirement: At least 27 units of courses in one particular subject area will be completed for a grade. The plan for these 27 units must be approved by the CMS option representative.

Breadth requirement: At least 27 units of advanced courses in mathematics, engineering, science, or social science will be completed for a grade. The plan for these 27 units must be approved by the CMS option representative.

Preliminary Examination

All students must pass a preliminary examination on material from two CMS core classes in applied mathematics and two CMS core classes in computer science. The examination is administered by a committee consisting of at least three faculty selected by the CMS option representative. The exam will occur during the student's first year.

Candidacy Examination

All students must pass an oral candidacy examination to ascertain the breadth and depth of preparation for research in the chosen field. The examination will be administered by a committee that consists of at least four faculty, that is approved by the CMS option representative, and that satisfies Institute regulations. In particular, the chair of the candidacy committee must be a faculty member distinct from the student's research adviser. The examination will occur during the student's first three years.

CMS 290 is required for all CMS first-year graduate students during each term (fall/winter/spring).

Advising and Thesis Supervision

Upon admission, each student will be assigned a primary adviser in the option. This adviser will be replaced by a research adviser (possibly the same faculty member) once a direction of specialization is determined, and not later than the beginning of the second year. After completion of the candidacy exam, each student will form a thesis committee (possibly the same as the candidacy committee) that consists of at least four faculty, that is approved by the CMS option representative, and that satisfies Institute regulations. In particular, the chair of the thesis committee must be a faculty member distinct from the student's research adviser. The thesis committee will meet as needed, but no less than once a year, in order to advise the student.

A final oral examination will be scheduled and given after the Ph.D. thesis has been submitted for review to the student's adviser and thesis committee. The thesis examination is a defense of the thesis research and a test of the candidate's knowledge in his or her specialized fields. Normally, the defense will consist of a one-hour public lecture followed by an examination of the thesis by the thesis committee.

CONTROL AND DYNAMICAL SYSTEMS (CDS)

Aims and Scope of the Graduate Program

The option in control and dynamical systems (CDS) is open to students with an undergraduate degree in engineering, mathematics, or science. The qualifications of each applicant will be considered individually, and, after being enrolled, the student will arrange his or her program in consultation with a member of the faculty. In some cases the student may be required to make up undergraduate deficiencies in engineering science courses.

The CDS option, as part of the Computing and Mathematical Sciences department, emphasizes the interdisciplinary nature of modern theory of dynamical systems and control. The curriculum is designed to promote a broad knowledge of mathematical and experimental techniques in dynamical systems theory and control. In addition to taking courses in the CDS option, students must select a focus area (see below).

CDS Master's Degree

Students will be admitted to the option who expect to pursue the Ph.D. degree. The master's degree may be awarded in exceptional cases. The awarding of this degree requires fulfilling the Institute requirements for a master's degree, satisfying the focus requirements, and receiving a recommendation for awarding of the degree from the candidacy oral examination committee.

CDS Degree of Doctor of Philosophy

Institute requirements for the Ph.D. degree are described in the section on degree requirements. Approximately two years of course work are required, and two or more years are usually needed for preparation of the dissertation.

Admission to Candidacy

To be recommended for candidacy for the Ph.D. degree in control and dynamical systems, the student must, in addition to meeting the general Institute requirements, do the following:

- Complete the following courses: CDS 131, CDS 232, and CDS 231 or CDS 233.
- Complete the following CMS/ACM courses: CMS/ACM/IDS 107, CMS/ACM/IDS 113, or CMS 117.
- Complete an additional 36 units in CDS or other advanced courses in systems theory, dynamical systems, robotics, and/or applied mathematics.
- Complete the focus requirement, consisting of at least 27 units in a particular area outside of CDS. Courses taken to satisfy the focus must represent a coherent program of advanced study in the chosen area. Possible areas include biological systems, computer science, environmental sci-

ence, fluid dynamics, information and communications, networking, robotics, and space systems. The program of study must be approved by the student's counseling committee and the option representative.

- Preliminary examination. Toward the end of the first year, all incoming students must take a preliminary examination administered by the faculty. Its purpose is to ensure a solid and broad knowledge in control and dynamical systems, and in the event of a deficiency, to direct the students to necessary courses and reading.
- Prepare a research progress report.
- Pass an oral examination on the major topic of the student's research. The oral examination is normally taken no later than the end of the third year of graduate academic residence at the Institute.

In addition, CMS 290 is required for all CDS first year graduate students during each term (fall/winter/spring).

Advising and Thesis Supervision

Upon admission, each student is assigned an adviser in the option, who will approve the initial course of study by the student. A preliminary exam given during the first year of study will be used to evaluate the student's preparation for continued study.

The adviser will be replaced by a research adviser and a candidacy committee when the direction of specialization is determined, not later than the beginning of the second year. The candidacy exam is normally taken during the third year of study. The candidacy committee will be the judge of the completion of the engineering focus requirement, necessary before advancement to candidacy. The student's candidacy committee may be reconstituted as the thesis committee after the candidacy exam has been successfully completed.

At the early stages of thesis preparation, the student's thesis committee will meet as needed to advise the student of his or her progress and to deal with any problems that might have arisen.

A final oral examination will be given after the thesis has been formally completed. The thesis examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in the specialized field of research. Normally this defense will consist of a one-hour public lecture followed by an examination of the thesis by the thesis committee.

CDS Subject Minor

A student majoring in another option at the Institute may elect a subject minor in control and dynamical systems. He or she must obtain approval from the CDS faculty of a course of study containing at least 54 units of courses that are required for the CDS Ph.D. (see Advancement to Candidacy) or advanced courses with a CDS listing

ELECTRICAL ENGINEERING (EE)

Aims and Scope of the Graduate Program

Award of the Bachelor of Science degree may be followed by graduate study leading to the Master of Science degree in electrical engineering, and the more advanced degrees of Electrical Engineer or Doctor of Philosophy. Because admission to graduate studies in electrical engineering at Caltech is extremely competitive, the Admissions Committee attempts to select those applicants it judges both best qualified and best suited for the graduate program. Applicants should submit Graduate Record Examination scores.

EE Master's Degree

Normally, the master's degree in electrical engineering is completed in one academic year. The principal criteria for evaluating applicants for the MSEE are the excellence of their preparation for the math- and physics-oriented nature of Caltech's graduate courses, and the judgment of the Admissions Committee on their ability to successfully pursue and benefit from the course program. The Institute does not normally admit an applicant to the master's degree in a field in which the applicant already has a master's degree from another U.S. institution. Financial aid is seldom offered to those who intend to complete their graduate work with a master's degree. A joint B.S./M.S. degree is not available in electrical engineering.

135 units (100 or above) are required as approved by the electrical engineering graduate student adviser. No more than 30 units of pass/fail grades may be counted toward this requirement. Units toward this are not transferable from other schools. At least 54 units of EE letter-graded courses (courses listed or cross-listed as EE) labeled 100 or above and not counting EE 291 are required. EE 105 abc, Electrical Engineering Seminar, is also required. Students are urged to consider including a humanities course in the remaining free electives.

Students who have been admitted to the M.S.-only program must reapply if they are interested in the Ph.D. program.

EE Degree of Electrical Engineer

The engineer's degree may be awarded in exceptional cases. The awarding of this degree requires fulfilling the Institute requirements for an engineer's degree and receiving a recommendation for its awarding from the candidacy oral examination committee.

EE Degree of Doctor of Philosophy

As a rule, applicants who wish to undertake research work leading to a degree of Doctor of Philosophy in electrical engineering are admitted initially only for the MSEE. They are, however, evaluated according to additional criteria, the most important of which is the applicant's interest in and potential for research in one of the areas

described below. The statement of purpose required as part of the application should clearly address this match. Considerable weight is also given to the opinions expressed in the applicant's letters of recommendation.

During the Ph.D. applicant's master's degree year, evaluation continues. It is based in part on performance in courses and in part on a one-hour oral presentation scheduled early in the second quarter. As the year progresses, the electrical engineering faculty get to know the student, and the student makes contact with the professor in his or her area of research interest. Upon acceptance into a research group, the student begins research work and defers receiving the master's degree until formal admission into the Ph.D. program. In the event that the Adviser is not an EE faculty member, the student should meet with the EE Option Representative and develop an oversight plan to monitor progress. Before the end of his or her second academic year of graduate study, the student normally takes the Ph.D. qualifying oral examination. This must, however, be done no later than the end of the third academic year.

Ph.D. applicants who already hold a master's degree in electrical engineering from another U.S. institution may be admitted directly to the Ph.D. program, but must provide sufficient information to obtain advance acceptance into a research group.

Financial aid available to a Ph.D. applicant includes teaching assistantships and fellowships. TA duties consist of grading papers or lab instruction but not classroom lecturing. A fellowship may be supplemented by a teaching assistantship, and either or both include a full tuition scholarship. Tuition scholarships alone are not available. If financial aid is not requested, or if the box on the application form labeled "willing to come without aid" is checked, information on the source of funds for each year of intended graduate study must be included.

Candidacy

To be recommended for candidacy for the doctor's degree, the applicant must satisfy the following requirements (and pass the Ph.D. qualifying oral examination) no later than the end of the third academic year:

- Complete 18 units of research in his or her field of interest.
- Obtain approval of a course of study consisting of at least 135 units of advanced courses in electrical engineering or the related subjects approved by the Ph.D. adviser, with at least 54 units of letter-graded EE courses numbered 100 or above (not counting EE 291). Only up to 27 units in research (e.g., EE 291) may be counted in this total. No more than 30 units of pass/fail grades may be counted toward this requirement. The courses taken to satisfy the math requirement below and courses taken to fulfill the Master of Science degree requirement may be included to satisfy this require-

ment. Units toward this requirement are not transferable from other schools.

- Pass 27 units of mathematics courses, as approved by the student's research adviser, with letter grade no lower than C.
- Pass a qualifying oral examination covering broadly the major field. Students are strongly encouraged to do this before the end of the second year of residency.

Ph.D. Committee

The Ph.D. qualifying oral exam and the final defense exam are conducted by committees that are set up by the student and approved by the option representative. Members of these Ph.D. committees also serve as second or backup mentors in cases where such additional advising and problem solving are appropriate.

Thesis and Final Examination

The candidate is required to take a final oral examination covering the doctoral thesis and its significance in and relation to his or her major field. This final examination will be given no less than two weeks after the doctoral thesis has been presented in final form, and before its approval. This examination must be taken at least four weeks before the commencement at which the degree is to be granted.

Advising and Thesis Supervision

Periodic meetings between the advising faculty and the graduate student are an integral part of the Ph.D. program. These meetings should be at sufficiently frequent intervals, as determined by the student and adviser. Students are also encouraged to meet with other members of the Ph.D. committee, the option representative, the executive officer, or Caltech's ombudsperson to discuss problems relating to satisfactory progress.

EE Subject Minor

A student majoring in another option at the Institute may elect a subject minor in electrical engineering. He or she must obtain approval from the electrical engineering faculty of a course of study containing at least 45 units (over the 100 level) of advanced courses with an EE listing (excluding 291). At least 36 of these should be for letter grades no lower than C. Freshman classes cannot be counted toward this.

ENVIRONMENTAL SCIENCE AND ENGINEERING (ESE)

Aims and Scope of the Graduate Program

The ESE graduate program trains doctoral students to solve fundamental problems in environmental science and engineering. The problems cut across traditional disciplinary boundaries and span space scales ranging from global to local. Students are trained

to acquire a broad base of knowledge of environmental systems, including Earth's atmosphere, oceans, and biosphere. They deepen their knowledge in one or more focus areas, culminating in research leading to a Ph.D. thesis. Reflecting the interdisciplinary nature of research in the ESE program, the program unites faculty from the divisions of Geological and Planetary Sciences, Engineering and Applied Science, and Chemistry and Chemical Engineering.

Admission

Applicants for admission to the ESE program should have undergraduate preparation in science, engineering, or mathematics. Admission is limited to students intending to pursue the Ph.D. degree. All applicants are required to submit scores for the Graduate Record Examination (GRE) General Test. Applicants from non-English-speaking nations are additionally required to submit results for the Test of English as a Foreign Language (TOEFL).

Advising

An academic adviser is appointed for each incoming student to assist in designing his or her academic program. The research adviser is chosen by mutual agreement of the student and adviser during the second year of graduate study, after passing the Ph.D. qualifying examination. The Thesis Advisory Committee (TAC), consisting of four Caltech faculty members including the research adviser, should be constituted and meet with the student soon after the student passes the qualifying examination; thereafter, it should meet with the student annually to review progress and provide guidance and support. Committee membership may be changed if the student's research interests change. The TAC generally serves to recommend the student's advancement to candidacy; it may also serve as the examining committee for the final thesis defense.

ESE Master's Degree

Students enrolled in the Ph.D. program may be awarded a master's degree if they have satisfied the basic Institute requirement of 135 units of work in courses numbered 100 or higher. These courses must include those specifically required in the ESE Ph.D. program.

ESE Degree of Doctor of Philosophy

For the Ph.D. degree, the student must (1) satisfy the course requirements, (2) pass the qualifying examination, (3) advance to candidacy, and (4) complete a thesis and successfully defend it in a final oral examination.

Course Requirements

During their first year, students, in consultation with their academic advisers, must design a program of graduate study that includes a minimum of 135 units of graduate work to be completed before the end of their third year. The course program should take into account the students' individual backgrounds and focus areas, educate them broadly in fundamental questions and methods of contemporary environmental science and engineering, and prepare them for their research.

The course program must include the core courses ESE 101, 102, and 103. Attendance at the weekly research seminars (ESE 104 and 110 abc) is required for first-year students and is expected of all graduate students. All students are expected to have knowledge of methods of applied mathematics and statistics on the level of courses such as Ge 108 and Ge/ESE 118. In cases of unusual preparation, students may petition to substitute a similar but more advanced course for one of the required courses.

Additionally, students are required to take 36 units of elective courses from two of the three groups below:

- Environmental Biology: ESE/Bi 166, ESE/Bi 168, Ge/ESE 170;
- Environmental Chemistry: ESE/Ch 175, ESE/Ch 176, ESE/Ge/Ch 171;
- Environmental Physics: ESE 130-138, Ge/ESE 139, Ge/ESE 150, ESE/ChE 158.

The remaining units of graduate work can be fulfilled by a combination of elective courses in ESE or related disciplines, reading or laboratory courses (ESE 100), and research (ESE 106, 300). Of the total required 135 units, no more than 45 units may be in research. No more than 27 research units may be taken during the first year of graduate study. Exceptions may be granted by petition.

It is expected that each graduate student will, as part of the Ph.D. graduation requirement, serve as a teaching assistant for one course per year, following completion of the qualifying exam.

Ph.D. Qualifying Examination

The Ph.D. qualifying examination must be taken during the first term of the student's second year of residency. This examination consists principally of an oral defense of two research propositions, each advised by a different faculty member. Written abstracts must be submitted for both propositions, and one of them must be described in the form of a research report or proposal. The qualifying exam also covers the material of the ESE core courses and of the elective courses the student has taken. In preparation for the qualifying examination, students are encouraged to register for nine units of research (ESE 106) in their second and third terms of residency.

Advancement to Candidacy

Students are recommended to advance to candidacy following the successful completion of a candidacy exam with their Thesis Advisory Committee (TAC). The exam, consisting of both a written Ph.D. thesis proposal and an oral presentation of this plan is required, and must be approved by all TAC members. Advancement to candidacy, including all required course work, should be completed before the end of spring term in the student's third year of residency.

Thesis and Final Examination

Copies of the completed thesis must be provided to the examining committee two weeks before the final oral examination. The final oral examination focuses on the work of the thesis and, according to Institute regulations, must be held at least two weeks before the degree is conferred.

ESE Subject Minor

Graduate students majoring in another option at the Institute may elect a subject minor in ESE. The ESE minor is intended to supplement one of Caltech's graduate degrees and is designed for students who wish to broaden and deepen their expertise with knowledge in ESE. To complete an ESE subject minor, graduate students must enroll in a program of study approved by the ESE option representative, which is to include at least 36 units over two or more terms of graduate-level ESE classes (ESE 100 and above) and 18 units over two or more terms of research under ESE 106 or ESE 300. At least one of the graduate-level ESE classes must be ESE 101, ESE 102, or ESE 103.

GEOLOGICAL AND PLANETARY SCIENCES (GPS)

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

Aims and Scope of the Graduate Program

Students in the Division of Geological and Planetary Sciences study the earth and planets to understand their origin, constitution, and development, and the effect of the resulting physical and chemical characteristics on the history of life, on the environment, and on humanity. Broad training in the fundamental sciences enriched by more specialized course work within the division forms the basis of the educational program. Students are encouraged to work with complex and often incomplete data sets, to undertake research in natural settings such as in the field or at sea, and to use the many modern laboratory facilities available within the division. Programs of study and research are pursued in environmental science and engineering, geobiology, geochemistry, geology, geophysics, and planetary science. The curriculum is flexible so that students with diverse degrees in science and engineering

may carry out graduate work within the division. Interdisciplinary studies are encouraged and students may carry out academic and research programs within and between different divisions. The objective is to train students for future employment in academic research, government, and industry.

Admission and Entrance Procedures

Only students who intend to work full-time toward the Doctor of Philosophy (Ph.D.) degree are admitted. The application submission deadline for the GPS Division is January 1. The admission process follows Institute regulations. Applicants are required to submit Graduate Record Examination (GRE) scores for the general test. Individual option requirements for GRE subject tests are specified below:

Environmental Science and Engineering—Not required.

Geobiology—Not required.

Geochemistry—Subject tests are strongly recommended but not required.

Geology—Not required.

Geophysics—Not required.

Planetary Science—Subject tests are strongly recommended but not required.

Applicants from non-English-speaking nations are required to submit Test of English as a Foreign Language (TOEFL) scores.

Based on their applications and interests, students enter one of the major subject options of the division and are given an academic adviser who is a professorial faculty member associated with the option. The six options are environmental science and engineering, geobiology, geochemistry, geology, geophysics, and planetary science. Students may later change options, but must first obtain approval from the new option. Each student must plan to satisfy the requirements for the Ph.D. degree in one option.

Entering students in the week preceding the beginning of instruction for the first term meet with their option representatives to discuss their preparation in the basic sciences and select a series of courses that will best prepare them for research in their chosen field while meeting the requirements set forth below.

First-year graduate students are encouraged to register for at least nine units of research (Ge 297) in each term of residence. The primary objective is to communicate to the students the excitement of discovery based on original investigations and to provide a broad scope of research aims. An important byproduct can be the formulation of propositions for the Ph.D. qualifying oral examination or orientation toward Ph.D. research.

Advising and Thesis Supervision

The option representative for each incoming student will act as the academic adviser in the first term. An academic adviser will be assigned by the start of second term. This appointed adviser will continue as mentor with broad responsibility for a student's academic welfare throughout the graduate program. During the second year, after passing the qualifying examination, each student should identify a professor as thesis adviser, who will normally provide a graduate research assistantship and the opportunity for continuing research. In consultation with the two faculty advisers, each student then forms a Thesis Advisory Committee (TAC), composed of at least four Caltech professors (chaired by the academic adviser). External scientists closely involved in the student's research may also be appointed. Members of the TAC serve as advisers, counselors, and resources, and its membership may be changed if a student's research interests change.

The TAC meets with the student at least once each year for a progress review, and informally whenever the student needs or requests assistance or guidance. In addition, the faculty members in each option have their own systems for annual evaluations of student progress. A few months before completion of the thesis dissertation, the thesis examining committee will be chosen, usually including the members of the Thesis Advisory Committee.

All students are urged to consult with division faculty in the following sequence if they have any problems: thesis and academic advisers, Thesis Advisory Committee, option representative, academic officer, and division chair. If these division personnel cannot resolve a problem, then the student should turn to Institute offices.

GPS Master's Degree

Students enrolled in the Ph.D. program may be awarded a master's degree when they have satisfied the basic Institute requirement of 135 units. These courses must be part of a plan of study approved by the option representative, numbered 100 or higher, and part of those used to satisfy the Ph.D. requirement in one of the options of the division. Specifically required are two courses from the list Ge 101, Ge 102, Ge 103, Ge 104, or ESE 101, ESE 102, ESE 103.

An application for admission to candidacy for an M.S. degree must be submitted in REGIS according to the academic calendar in the Caltech Catalog (see pages 4–5).

GPS Degree of Doctor of Philosophy

Division Requirements

For a Ph.D. degree, the student must 1) pass the qualifying oral examination, 2) satisfy course requirements of the division and of an option, and 3) complete a thesis and successfully defend it in a final oral examination. Recommendation to the Dean of Graduate Studies for admission to candidacy occurs after the student has

satisfied the first two requirements and has been accepted for thesis research by a division faculty member, who then becomes the student's thesis adviser.

The qualifying examination consists of oral and written defense of two research propositions, supplemented by a written description of one of them. Students are encouraged to consult with various faculty members concerning their ideas on propositions, but the material submitted must represent the work of the student. There must be a different faculty member associated with each of the two propositions. The exam is normally taken early in the first term of the second year of residence and is administered by the qualifying examination committee, which has members from the six options of the division. A more detailed outline of the qualifying examination is available on the division website.

By the end of the fall term of the second year, students are expected to select a thesis adviser(s) and before the end of the second year, the Thesis Advisory Committee will be selected, as outlined above. The division encourages students to engage in research early in their graduate careers. Students making normal progress will submit papers to refereed journals that have been approved by a faculty member of the division. The final oral examination for the doctorate by the thesis examining committee will be scheduled no sooner than two weeks following submission of the thesis (approved by the thesis adviser) and, in conformity with Institute regulations, it must be scheduled at least two weeks before the degree is to be conferred.

Candidates are expected to publish the major results of their thesis work. The published papers should have a California Institute of Technology address. Published papers may be included in the thesis.

By the end of the first academic year (third term): submission by the student of (1) tentative titles of propositions for review by the qualifying examination committee and (2) a list of courses planned to satisfy the Ph.D. requirement, for review by the option.

By the end of the second academic year: (1) passage of oral exam; (2) approval by the option of courses planned to satisfy candidacy requirements; (3) submission of a tentative thesis topic and adviser, and Thesis Advisory Committee.

By the end of the third academic year: (1) satisfactory completion of course requirements; (2) satisfactory completion of other requirements including selection of thesis topic and adviser, and Thesis Advisory Committee; (3) admission to candidacy. A student who has not been admitted to candidacy by the end of the third year will need permission of the academic officer to register.

By the end of the fourth academic year: satisfactory progress toward completion of thesis.

After completing the fifth academic year, the student must formally petition to register for each subsequent year. Financial aid will normally not be extended beyond the sixth year.

The student's program and progress will be reviewed annually

by his or her option and by the Thesis Advisory Committee. In cases where, in the opinion of the faculty in the option, the student is clearly not showing adequate progress, they may recommend to the division chair that the student be denied permission to continue in the Ph.D. program based upon their overall assessment of the student's performance.

Basic Division Course Requirement

During the first year, every graduate student will take two of the seven basic introductory courses Ge 101–104 and ESE 101–103, in areas in which the student has not had substantial training. These should be completed during the first year. Throughout their graduate careers, students are expected to attend departmental seminars and seminar courses led by visiting scientists.

Beginning in the second academic year, students are required to serve as teaching assistants for one quarter per year they are in residence.

GPS Requirements of the Major Subject Options

Geobiology

In addition to the general Institute and basic division requirements, candidates for the Ph.D. degree in geobiology must successfully complete a minimum of 90 units at the 100 or greater level, including Ge 104; either Bi/Ch 110, Bi/CNS/NB 195, or Ge/ESE 118; and two courses from each of the following three subject menus:

Geology: Ge 106, 112, 114 ab, 124 ab, Ge 125.

Chemistry: Ge/ESE 143, 149, Ge 140 ab, ESE/Ge/Ch 171, 172, ESE/Ch 175, 176.

Biology: ESE/Bi 166, 168, Ge/ESE/Bi 178, Bi 117, ESE 103.

Other classes may be substituted for these menu requirements with the approval of the option representative. A student with substantial prior experience in geobiology (e.g., an M.S. degree) may use prior course work to substitute up to 45 of these units with the approval of the geobiology option representative. All students must have a basic knowledge of organic chemistry at the level of Ch 41 a. This requirement may be met by previous course work or through successful completion of this class. Geobiology students must complete one term (6 units) of Ge 109 (Oral Presentation) as an independent study with a faculty member of their choosing, typically the thesis adviser.

Geochemistry

In addition to general Institute and basic division requirements, candidates for the Ph.D. degree in geochemistry are required to take one term of Ge 109 in the geochemistry option and are required to demonstrate an understanding of the field through a total of 90 units of course work at the 100 level or higher spread over four of the subdisciplines offered in the option: petrology/min-

erology, isotope geochemistry, cosmochemistry, water chemistry/oceans, atmospheres, biogeochemistry, or advanced chemistry. All students must have a basic knowledge of chemistry at the level of Ch 21 and mathematics at the level of Ge 108. If appropriate, Ch 21 abc may be included as part of these units, and other courses below the 100 level may be included at the discretion of the option representative. With the approval of the geochemistry option representative, a student with substantial prior experience in some of the subdisciplines may use prior course work to substitute for up to 45 of these units and students entering with a master's degree in science or mathematics may be exempt from up to 45 units. In the oral candidacy exam, the student will be subject to examination in all four of the chosen subdisciplines.

Geology

The geology option requirements are (1) two of Ge 102, 103, 104, or ESE 101, ESE 102, ESE 103, which also satisfy the basic division requirement; (2) 36 units of advanced field geology, in the form of three terms of Ge 121 abc taken from three different instructors; (3) 54 additional units in 100- or 200-level science, math or engineering courses in any field at Caltech. Ch 21 abc may be included as part of these units, and other courses below the 100 level may be included at the discretion of the option representative. Courses that cannot be used to satisfy these requirements include research and reading courses, and certain courses constituting basic preparation in the field of geology, such as Ge 106, Ge 112, Ge 114 ab, and Ge 115 ab. A grade of C or better is required for all course work that satisfies these requirements. Knowledge of basic physics, mathematics, and data analysis at the level of Ge 108 and Ge/ESE 118 is required of all Ph.D. candidates in geology. Students entering the geology option with a master's degree in a science or mathematics may be exempt from up to 45 units at the discretion of the option representative. Geology students are required to give a 30-minute presentation, including 10 minutes of discussion, on their research at the Geoclub Seminar series before admission to candidacy.

Geophysics

In addition to general Institute requirements, candidates for the Ph.D degree in geophysics must successfully complete the following: (1) two of the following basic introductory courses: Ge 101, 103, 104, or ESE 101–103, and one term of Ge 109 per year from the second year until the last year prior to obtaining the degree; (2) either Ae/Ge/ME 160 ab, APh 105 ab, MS 115, or a subject equivalent; (3) three of Ge 161, Ge 162, Ge 163, or Ge 164; (4) Ge 111 ab; (5) the choice between five additional 100- or 200-level science or mathematics courses or a minor in any field at Caltech (for example, computational science and engineering). It is highly recommended that (1)–(4)

be fulfilled in the first year and (5) in the second year. A grade of C or better is required for all course work that satisfies these requirements. Knowledge of basic physics, mathematics, and data analysis at the level of Ge 108 and Ge/ESE 118 is required of all Ph.D. candidates in geophysics. This requirement may be met by previous course work or through successful completion of these classes. Students may substitute another course for a required course if they can demonstrate to an option representative that they have already had the material in the required course.

Planetary Science

In addition to general Institute and basic division requirements, candidates for the Ph.D. degree in planetary science must satisfy the following course requirements: Ge 101, Ge 102, and courses in planetary formation and dynamics (Ge/Ay 133), planetary atmospheres (Ge/ESE 150), planetary interiors (Ge 131), and planetary surfaces (Ge 151). In addition, students shall successfully complete 45 units of 100-level or higher courses in a coherent field of specialization. This requirement may be satisfied by completion of a subject minor or through a set of courses chosen in consultation with and approved by the adviser and the option representative. All candidates are expected to possess knowledge of physics and mathematics at the level of Ge 108, and higher-level mathematics and physics courses are strongly encouraged. This requirement may be met by previous coursework or through successful completion of this class. All candidates are expected to attend the planetary sciences seminar regularly and register for six terms of Ge 109 (planetary sciences section of oral communication) for a total of 6 units, nominally in the first year and second year. Satisfaction of the oral presentation coursework requirement includes at least one 30-minute presentation by the student in the planetary sciences seminar. Typically, students will present on their research work each year after the first year.

GPS Subject Minor

A student may, with the approval of the Division of Geological and Planetary Sciences, elect a minor in any one of the major subjects listed above. Such a subject minor will include at least 45 units in courses at the 100 level or higher. Normally, a member of the division faculty affiliated with the minor will participate in the student's oral thesis defense.

HISTORY (H)

The program for a subject minor in history must be approved by the executive officer for the humanities before the admission to candidacy. In addition to meeting general Institute requirements, the student must complete satisfactorily, with a grade of C or better, 45 units in advanced courses in history.

HISTORY AND PHILOSOPHY OF SCIENCE (HPS)

Graduate students in science, mathematics, or engineering may take a minor in history and philosophy of science (HPS). The graduate minor is devoted to the study of the historical evolution and philosophical underpinnings of the physical and biological sciences. Historical work in the minor includes the origins of experimental practice, the social and institutional contexts of science, the origins and applications of quantitative methods, specific developments since antiquity in physics, biology, and chemistry, as well as biographical and comparative studies. Philosophical research deals with issues in causation, explanation, scientific inference, the foundations of probability and decision theory, philosophy of mind and psychology, philosophy of neuroscience, and scientific fraud and misconduct.

The minor thus fosters the acquisition of broad knowledge about the scientific enterprise and related foundational problems, as well as more detailed analysis of the progress of and philosophical problems in particular branches of science. It is a valuable supplement to a technical degree since it helps equip students to understand the nature of scientific progress and to grapple with the conceptual basis of science and its wider ramifications. Students who successfully complete the HPS minor will be recognized with official credit for the achievement on their transcripts.

Requirements

Graduate students who take an HPS minor are expected to complete Hum/H/HPS 10, HPS 102 ab, HPS/PI 120, at least three units of HPS 103, and 18 units of additional work in HPS, to be completed by taking courses in HPS/H or HPS/PI numbered 99 or higher. Students need not complete the requirements for the minor within the first two years of graduate study.

MATERIALS SCIENCE (MS)

Aims and Scope of the Graduate Program

The graduate program is designed to give students an understanding of general phenomena in synthesis–structure–property relationships in all materials, plus a detailed understanding of phenomena for at least one broad class of materials such as: physical materials science (solid state physics, quantum mechanics); mechanical materials science (micromechanics, continuum mechanics); soft materials (polymer chemistry/physics, chemical bonding); or oxide materials science (mineralogy/mineral physics). After completing the Ph.D. program, students have pursued careers in teaching and research at colleges and universities, in research for government and industry, in the operation and control of manufacturing processes, and in management and development positions in the materials industry.

Students may enter the graduate program in materials science with undergraduate preparation in physics, chemistry, engineering, or materials science. Students interested in terminating their graduate study at the master's level are not normally admitted. Students in the Ph.D. program are required to complete a set of core courses, pass an oral candidacy examination, complete a thesis describing original research in materials science or a related field, and publicly defend their thesis work.

MS Preparation for the Graduate Program

Students who have not specialized in materials science as undergraduates, as well as those who have, may be admitted for graduate study. As preparation for advanced study and research, entering graduate students are expected to have a thorough background in undergraduate mathematics, physics, and engineering. An outstanding four-year undergraduate program in mathematics and sciences is also a suitable background. The qualifications of each applicant will be considered individually, and, after being enrolled, the student will arrange his or her course of study and research in consultation with members of the faculty and the Materials Science option representative.

MS Master's Degree

The degree of Master of Science in Materials Science is only awarded to students who do not already have an M.S. degree in Materials Science. The degree will be awarded upon request by students who have fulfilled the requirements. Only in exceptional cases is there admission to the M.S. program as the final degree objective.

Each student is assigned to a member of the faculty who will serve as the student's adviser. The adviser and option representative for materials science will approve his or her course of study. Study for the degree of Master of Science in materials science will ordinarily require at least three terms of courses. The courses shall be chosen from the list of core courses below, although 27 units of research (MS 200 or equivalent) may be substituted for 27 units of lecture or laboratory courses. Completion of 137 units of these courses within two years with no grade less than a C constitutes the academic requirements for the M.S. degree.

Core Courses

1. MS 131, MS 132, MS 133.
2. APh/MS 105abc, or ChE/Ch 165 and ChE/Ch 164 and APhMS 105c, or Ae/ME 118 and ChE/Ch 164 and APh/MS 105c.
3. Two quarters of courses focused on specific materials, such as APh 114 ab; Ch 120 a; Ch 121 ab; Ch/ChE 147, ChE/Ch 148; Ge 114, Ge 214.
4. Two quarters of courses focused on internal interactions

in materials, such as Ph 125 ab, Ch 125 ab or Ae/Ge/ME 160ab.

5. 18 units of courses comprising either the third terms of the sequences taken in 3 and 4 above, or other courses appropriate for the student's research interests, such as MS 121, MS/APh 122, MS 125, MS 142, MS/ME/MedE 116, or APh/MS256.
6. ACM/IDS 104 and ACM 100ab, or ACM/IDS 101ab, or ACM/EE 106ab, or Ph 129ab, or may be waived at the discretion of the student's adviser and option representative.
7. MS 110 (2 units) or APh 110 (4 units).

MS Degree of Doctor of Philosophy

The doctoral program in materials science consists of a series of preparatory classes, followed by an oral candidacy exam, a written thesis, and a final oral thesis defense. The goals of this program are to develop excellence in a chosen field of specialization; to develop tools with which to assess problems outside the student's field of specialization; to develop sufficient strength in the physical sciences for self-education beyond formal training; and to cultivate the motivation and foresight to become a productive and influential leader. As such, the graduate program in materials science is designed to be a doctoral program and students are only admitted into the doctoral program. There is no separate master's program in materials science.

The Ph.D. degree in materials science is focused on research. Study and research programs for the Ph.D. degree are individually planned to fit the interests and background of the student. A comprehensive research project resulting in an original contribution to the field documented by a dissertation is required.

Residency

A minimum of three academic years in residence as a graduate student are required by the Institute, and two or more additional years are usually needed for preparation of the thesis.

Language Requirement

There is no language requirement for the Ph.D. degree.

Minor

No minor is required for the Ph.D. degree. Students are, however, encouraged to take advanced courses appropriate to their particular interests.

Advising and Thesis Supervision

An interim adviser is appointed for each student upon admission to a graduate degree in materials science (typically the materials science option representative). The interim adviser will serve as the

primary mentor until the student finds a research adviser. In the first year (no later than the third term), each student must choose a research adviser who will have primary responsibility for supervising the student's course program and research. The important adviser–advisee relationship requires effort from both parties, and some general expectations are outlined earlier in this section of the catalog. In consultation with their research adviser, the student should then form a Ph.D. Thesis Advisory Committee. This four member committee should include: (i) the student's adviser, and (ii) at least three members of the Caltech professorial faculty. The research adviser and the Thesis Advisory Committee provide the majority of mentoring to the student, offering advice on research, progress toward the Ph.D., future careers, and other aspects of life in graduate school and as a professional scientist.

Requirements for Candidacy for the Ph.D. Degree

To be recommended for candidacy for the Ph.D. degree in materials science, the student must, in addition to meeting the general Institute requirements, do the following:

- a. ***Courses.*** To continue in the graduate program, the student must maintain a B– average for each term. Advancement to candidacy requires the successful completion of the program listed under “Core Courses” above. Alternatively, if the student has taken equivalent courses elsewhere, he or she may prove competency to the instructor of the equivalent course at the Institute and request a waiver of the required course. With the Core Course requirements 1-7, students must complete a minimum of 137 units of courses, numbered 100 or above, before presenting themselves for Ph.D. candidacy. The coursework towards the Ph.D. degree in materials science is typically completed within the first two years of residency at Caltech.
 - All courses must be passed with a grade of at least a C, except for courses taken on a pass/fail basis.
 - Students must complete the degree progress report online.
 - Alternate Subjects or Areas
 - ~ Students entering the program with advanced preparation may choose either to substitute more advanced courses in the topical areas shown or demonstrate competency to the course instructor.
 - ~ Students may petition the materials science option representative to accept alternative subjects or areas, but such petitions must be submitted before the student registers for the courses.
- b. ***Oral Candidacy Examination.*** This examination should be taken no later than the end of the student's second year of

residence. The student's research adviser must be on the examining committee, but cannot serve as chair of the committee. The examination is based on the student's research and on coursework, and how it is related to the student's planned research area. The student's research adviser must be on the examining committee, but cannot serve as chair of the committee. The examination is based on the student's coursework, and how it is related to the student's planned research area. The student will be expected to deliver a half-hour oral presentation describing his/her research to date and to answer questions related to this work. This portion of the examination will be followed by more open-ended questions to test general proficiency in Materials Science. Students who fail the oral examination on their first attempt will be given additional guidelines for further study and an opportunity to retake the examination a second and final time if the committee so recommends. Should a student fail the oral examination a second time, he/she cannot continue with doctoral studies leading to the Ph.D. Upon recommendation of the examining committee, however, the student may be granted a terminal master's degree. The approval of the Materials Science option representative is necessary for registration beyond the third year of graduate residence without successfully completing the candidacy exam.

- c. **Research Competence.** The student must have a doctoral research adviser, and must have completed at least 18 units of MS 200. Students who fulfill the requirements above will be recommended for candidacy to the doctoral program and a master's degree (if applicable) in Materials Science.

Ph.D. Thesis Requirements

The candidate is to provide a draft copy of his or her completed thesis to the members of the examining committee (typically the same as the Thesis Advisory Committee) at least two weeks before the final oral examination. The date of the examination and the composition of the examining committee will not be approved by the Dean of Graduate Studies until the thesis is submitted in completed form, i.e., ready for review by the Dean, the members of the thesis committee, and the Graduate Office proofreader. Registration is required for the term in which the thesis defense is undertaken, but is not normally allowed beyond the last date of the term. For more information, please see the section entitled "Information for Graduate Students" in the Caltech catalog.

Ph.D. Final Examination

The candidate is required to take a final oral examination covering the doctoral thesis and its significance in and relation to his or her major field. It will consist of a public thesis seminar and an

associated oral examination on the thesis and related fields. The examining committee must consist of the student's adviser and three members of the Caltech professorial faculty. The chair of the examining committee must be a Caltech professorial faculty member distinct from the adviser. This examination will be held at least two weeks after the doctoral thesis has been presented in its final form, and prior to its approval.

Registration beyond the Sixth Year of Graduate Residence

The annual approval of the student's Thesis Advisory Committee and option representative is necessary for registration beyond the eighteenth academic term of graduate residence at Caltech.

MS Subject Minor

A graduate student majoring in another option at the Institute may elect a subject minor in materials science. He or she must obtain approval from the materials science faculty of a course of study containing at least 45 units of advanced courses with a grade of C or higher. Normally a member of the materials science faculty will participate in the candidacy examination in the student's major department.

- Students cannot use courses required by their major option in fulfillment of this requirement.
- Students interested in a minor must receive prior approval from the option representative in materials science, who will review and approve the proposed course of study.
- It is recommended that this course of study include advanced courses spanning different subfields of materials science.

MATHEMATICS (Ma)

Aims and Scope of the Graduate Program

The principal aim of the graduate program is to develop the student's ability to do original research in mathematics. Independent and critical thinking is fostered by direct contact with faculty members. (An indication of the current research interests of the faculty begins on page 163.) Faculty advisers help students plan their programs of study leading to a Ph.D. in mathematics. Entering students are advised by the graduate option representative, who assists them in selecting appropriate courses, depending upon their previous studies.

Ma Master's Degree

Entering graduate students are admitted directly to the Ph.D. program, since the Institute does not offer a regular program in mathematics leading to the master's degree. A master's degree may be awarded in exceptional circumstances either as a terminal degree

or preliminary to the Ph.D. Sufficiently advanced undergraduates may be admitted to graduate standing to pursue a master's degree simultaneously with the bachelor's program.

The recipient of a master's degree will be expected to take 135 units in advanced mathematics (numbered 110 and higher). Unless the student has placed out of some of them, these must include Math 110, 120, and 151 (the basic courses in analysis, algebra, and geometry) and at least two terms of discrete mathematics. Reading and/or research courses may only be included in this 135 units if approved by the executive officer for mathematics.

The general Institute requirements specify that the recipient of a master's degree must have taken at least 135 units of graduate work as a graduate student at the Institute, including at least 81 units of advanced graduate work in mathematics. This advanced work is interpreted as work with a course number greater than 109 and may include a master's thesis.

Ma Degree of Doctor of Philosophy

Course Program

The graduate courses are listed in section five. The three core course series—Ma 110 abc in analysis, Ma 120 abc in algebra, and Ma 151 abc in geometry and topology—are required of all graduate students. Students are expected to complete each of the core course series during the first year of study, unless they complete the corresponding qualifying exam upon entrance to the program (see section on qualifying exams). In addition, students are required to complete nine quarters of other advanced mathematics courses Ma 111 and above, at least two of which are in discrete mathematics: combinatorics, complexity, and computability, or logic and set theory. Unless these nine course quarters are given pass/fail only, they must be taken for grades. Reading and research do not normally qualify to meet these requirements. Under special circumstances (e.g., finishing the degree in three years), exceptions to these requirements may be considered by the graduate option representative. Beginning no later than the second year, students will be expected to begin independent research work and will be strongly encouraged to participate in seminars.

Qualifying Examinations

Qualifying examinations in the three core areas—analysis, algebra, and geometry/topology—emphasize mastery of the basic concepts and theorems and the ability to apply them to specific cases. Students are required to take and pass two of the three examinations, and for the third not taken, students must earn a B or better in all three terms of the corresponding course series. The exams are offered at the beginning of the Fall term and end

of the Spring term each academic year, with exceptional offerings made at other times of the year if needed and approved by the graduate option representative. The examinations must be attempted by the end of the Spring term during the first year of study, and completed by the end of the first academic year. Entering students are permitted to take one or more qualifying examinations at the beginning of the Fall term of their first academic year. If completed successfully, the student may drop the corresponding core course and will be excused from the remainder of the corresponding core requirement. Special exceptions or extensions to the qualifying examination timeline may be considered by the graduate option representative with support from the primary research adviser.

Teaching Requirements

Teaching is an integral part of the Mathematics graduate education. It is expected that students serve as teaching assistants in each term courses are offered unless alternative arrangements have been made with the option and approved by the executive officer.

Summer Study

Although there are no courses given in the summer, graduate students are expected to carry out studies and research in their chosen area of mathematics. In the summer after the first year, they will work under the guidance of a faculty member to investigate a possible area for their thesis research.

Thesis Advising and Tracking Committee

It is expected that by the fall quarter of the second year, students will find a member of the faculty who agrees to serve as their thesis adviser. The formal change of adviser process should be complete by the end of the second academic year.

The progress of all continuing students is assessed by the faculty each fall, and students will consult with their advisers about their progress and planning of their studies and research. Students receive help and advice not only from their thesis adviser and other faculty mentors, but also whenever needed from the graduate option representative and the executive officer. (See also the section with guidelines for graduate student advising.) In addition to the primary thesis adviser, each student will have a candidacy committee, Thesis Advisory Committee (TAC), and final defense committee. In most cases, the members of all of these committees are the same, but the student has the right to change the members. The student in consultation with his or her adviser will arrange the formation of the committee, which will have at least four members and meet the requirements listed in the subsection Graduate Policies and Procedure entitled 'Degree of Doctor of Philosophy.' At least two of the committee members should be members of the mathematics

professorial faculty and the chair of the committees must be a professorial faculty who is not the primary research adviser.

Admission to Candidacy

Before the end of their third year, students are expected to finish the process of applying for admission to candidacy for the Ph.D. degree. This formal step requires completion of the qualifying examinations, core courses, and advanced courses, as well as a satisfactory oral presentation to a committee of faculty members. The presentation will describe both the general area of the student's proposed thesis research and the specific problem or problems to be addressed. The candidacy meeting should be complete by the beginning of the fourth year of study. It normally takes place during the spring term of the third year. In some cases, during the summer term of the third year, but scheduling must be done by the end of the spring term. Special exceptions or extensions to the admission to candidacy timeline may be considered by the graduate option representative with support from the primary research adviser.

Thesis Advisory Committee Meetings

The Thesis Advisory Committee (TAC) will track the student's progress through annual meetings between the candidacy exam and final defense. It is the responsibility of the student to convene the TAC during the fourth and fifth year of study. The fourth-year meeting should take place no later than the end of the winter term of the fourth year. The fifth-year meeting should take place no later than the end of the fall term of the fifth year.

Thesis and Final Examination

At least two weeks prior to the final thesis defense, candidates for the degree of Doctor of Philosophy must deliver copies of their theses to their advisers, to the Graduate Office, and to the members of the committee that will conduct the final oral examination on the thesis. The examination must be held at least three weeks before the date on which the degree will be conferred and at least two weeks after the delivery of the copies of the thesis.

Ma Subject Minor

Students majoring in other fields may take a subject minor in mathematics. Minor programs must include 54 units of advanced work approved by a representative of the mathematics department, who will ensure that the work represents a concentrated study in one or more of the main fields of mathematics. A special oral examination in the subject minor will be given soon after completion of the minor program.

Ma Travel Grants

Special funding is available to graduate students to attend conferences and workshops in the United States or abroad (see Bohnenblust and Groce Travel Grants in the 'Prizes' subsection of this section).

MECHANICAL ENGINEERING (ME)

Aims and Scope of the Graduate Program

Mechanical Engineering (ME) research and study are offered through the Department of Mechanical and Civil Engineering (MCE). The degrees of Doctor of Philosophy (Ph.D.) and Master of Science (M.S.) are offered. In general, students who intend to work full-time toward the Ph.D. degree as a final degree objective are admitted to the mechanical engineering graduate program. The M.S. degree is typically only awarded to students who pursue the Ph.D. degree in mechanical engineering at Caltech and who do not already have an M.S. degree in mechanical engineering.

The aim of the graduate program in mechanical engineering at Caltech is to prepare students for research and professional practice in an era of rapidly advancing interdisciplinary technology. The program combines individual depth of experience and competence in a particular chosen major specialty, with a strong background in the basic and engineering sciences. It strives to develop professional independence, creativity, leadership, and the capacity for continuing professional and intellectual growth.

ME Preparation for the Graduate Program

Entering graduate students are expected to have a thorough background in undergraduate mathematics, physics, and engineering. While a strong undergraduate program in mechanical engineering should provide a suitable preparation, students who have not specialized in mechanical engineering as undergraduates may also be admitted for graduate study. For example, an outstanding four-year undergraduate program in mathematics and sciences may provide a suitable background as well. The qualifications of each applicant will be considered individually, and, after being enrolled, the student will arrange his or her program in consultation with a member of the faculty.

ME Master's Degree

The degree of Master of Science in mechanical engineering is only awarded to students who do not already have a M.S. degree in mechanical engineering. The degree will be awarded upon request by students who have fulfilled the requirements. Only in exceptional cases is there admission to the M.S. program as the final degree objective.

A minimum of 138 units of courses numbered 100 or above,

which meet the required master's program listed below, must be passed with a grade of at least C for completion of the master's degree in mechanical engineering. All units must be taken for grades, except for courses offered only on a pass/fail basis. The M.S. degree in mechanical engineering is typically completed within the first two years of residency at Caltech.

Each student's program must be approved by the adviser and option representative in mechanical and civil engineering before registering for the course.

Required Master's Program

- a) Graduate mechanical engineering core (54 units). These units should provide a solid base for the student's engineering interest. The courses should be selected from the Core ME subjects listed under the Degree of Doctor of Philosophy Description and Requirements section.
- b) Mathematics, engineering, and research electives (54 units). Students who have not taken the equivalent of ACM 100 ab are required to take ACM 100 ab for 24 units. Courses may be taken in Ae, AM, ACM, ME, MedE, MS, EE, ESE, APh, CDS, CS, ChE, and CNS. Students are encouraged to take research units, ME 300, up to a maximum of 27.
- c) Free electives (27 units). Any course with a number of 100 or greater may be selected, except that research units may not be included.
- d) Graduate Engineering Seminar, AM/CE/ME 150 abc (3 units).

ME Degree of Doctor of Philosophy

The Ph.D. degree in mechanical engineering is focused on research. Study and research programs for the Ph.D. degree are individually planned to fit the interests and background of the student. A comprehensive research project resulting in an original contribution to the field documented by a dissertation is required. A minimum of three academic years in residence as a graduate student are required by the Institute, and two or more additional years are usually needed for preparation of the thesis.

Advising and Thesis Supervision

An interim adviser is appointed for each student upon admission to a graduate degree in mechanical engineering. The interim adviser will serve as the primary mentor until the student finds a research adviser. It is the responsibility of the student to find an academic and research adviser within three terms of graduate residence at Caltech. In consultation with the adviser, the student must form a Ph.D. Thesis Advisory Committee within four terms of graduate residence at Caltech. This committee shall consist of at least three

members of the Caltech professorial faculty, with at least two members from the faculty in mechanical and civil engineering. The committee shall meet as requested by the student. Further, the committee shall meet annually to review progress and to approve the registration of the student beyond the fifth year of graduate residence at Caltech.

The adviser and the Thesis Advisory Committee provide the majority of mentoring to the student. In addition, the option representative and other members of the faculty are always available to provide advice and mentoring on any aspect of research, progress toward the Ph.D., future careers, and other aspects of life in graduate school and as a professional scientist.

Admission to Candidacy

To be recommended for candidacy for the Ph.D. degree in mechanical engineering, the student must, in addition to meeting the general Institute requirements, do the following:

- Obtain the agreement of a professorial faculty member to serve as his or her academic and research adviser before the end of the third term of graduate residence at Caltech. In consultation with the adviser, the student must form a Ph.D. Thesis Advisory Committee before the end of the fourth term. This committee shall consist of at least three members of the Caltech professorial faculty, with at least two members from the faculty in mechanical and civil engineering.
- Pass both subject and research components of the oral candidacy examination before the end of the eighth term of graduate academic residence at Caltech. If the student has chosen a subject minor, an examination on the subject of that program may be included at the request of the discipline offering the subject minor.
- Complete a minimum of 195 units of courses numbered 101 or above, that meet the required Ph.D. program listed below. All units must be taken for grades and passed with a grade of at least a C, except for courses offered only on a pass/fail basis. The course work towards the Ph.D. degree in mechanical engineering is typically completed within the first three years of residency at Caltech.

The faculty will evaluate the student's research progress, class performance, adviser's input, and oral candidacy exam results to determine whether a student will be admitted to or be able to maintain candidacy for the Ph.D. degree.

Required Ph.D. Program

- a) *ME Core Subjects* (54 units): Course work in core mechanical engineering subjects selected from the courses below. Pass with a grade of at least C, 36 units must be in a single

track (Depth requirement). An additional 18 units must be from the courses below but can be in any track, including the chosen Depth track.

Tracks:

Thermal-fluid sciences: ME119ab, Aph 115-116, ChE 164-165, ME 118, Phys 127abc, APh 105, ME 120ab, Ae/APh/CE/ME 101abc, ME/CE 163

Mechanics of solids, structures, and materials: Ae/AM/CE/ME 102abc, Ae/APh 104 abc, AM/CE 151, Ae/Ge/ME 160ab, ME/CE 163, Ae 165ab, ME/CE/Ge 174, Ae/AM/MS/ME 213ab, Ae/AM/CE/ME 214ab, Ae 220, Ae/CE 221, Ae/AM/ME 223, AM/CE/ME 252, ME/MS 260, ME/Ge/Ae 266ab

Robotics, Controls and Dynamics: CDS 112, CDS 131, CDS 141, CDS 231, CDS 232, CDS 233. ME/CS/EE 133 ab, CMS/CS/CNS/EE/IDS 155

- b) *Electives or Minor* (54 units): Additional engineering or science courses with course number 101 or above. Pass with a grade of at least C, courses that are approved by the thesis advisory committee. These courses are intended to provide further depth and incorporate breadth. These units can be used to satisfy a minor requirement in another option.
- c) *Advanced mathematics or applied mathematics* (27 units): Pass with a grade of at least C, chosen in consultation with adviser from the following list: ACM 101 or higher, CDS 232, Ma 108 or higher, Ph 129. The requirement in mathematics is in addition to the requirements above.
- d) *Graduate engineering seminar* (6 units): six terms of AM/CE/ME 150 abc, within the twelve terms or 3 years in residence at Caltech.
- e) *Research* (54 units). Successfully complete at least 54 units of research and demonstrate satisfactory research progress.

Registration Beyond the Sixth Year of Graduate Residence

The annual approval of the Ph.D. dissertation supervision committee is necessary for registration beyond the twenty-fourth academic term of graduate residence at Caltech.

Thesis and Final Examination

The thesis examination will be given after the thesis has been formally completed. This examination will be a defense of the doctoral thesis and a test of the candidate's knowledge in the specialized field of research. The format of the examination can be chosen from the following two options, by the student, in consultation with their research adviser: (i) a public seminar presented by the candidate, with an open question period, followed by a private

examination by the examining committee or (ii) a private presentation to the examining committee followed by the examination, with a public seminar on another date. The examining committee shall consist of a minimum of four voting members, three of whom must be Caltech faculty; two members must be from MCE. The thesis defense committee shall be chaired by a committee member who is an MCE Caltech professorial faculty member and not the student's adviser.

ME Subject Minor

A student majoring in another branch of engineering or another division of the Institute may, with the approval of the faculty in the department of mechanical and civil engineering and the faculty in his or her major field, elect mechanical engineering as a subject minor. The program of courses must differ markedly from the major subject of study or research, and must consist of at least 54 units of advanced courses (101 or above) approved by the faculty in mechanical and civil engineering.

MEDICAL ENGINEERING (MedE)

Aims and Scope of the Graduate Program

The Andrew and Peggy Cherng Department of Medical Engineering offers a program of study that leads to the Ph.D. The Medical Engineering option at Caltech is designed for students with an engineering background who are interested in applications of micro-/nanoscale science and technology in medicine, which forms the core of Caltech's multidisciplinary Medical Engineering. The program's goal is to close the gap between engineering and medicine. Our Medical Engineering research and education leverage Caltech's strengths in engineering, applied science, and other fundamental fields, to apply emerging technological advances to medicine, and to create innovative diagnostic, monitoring, and therapeutic systems. Our major tracks of research are: micro/nano medical technologies and devices, medical nanoelectronics, biomedical materials and biomechanics, fluidics and bioinspired design, and medical imaging and sensing.

MedE Master's Degree

Students are not normally admitted to work towards the M.S. degree. However, the M.S. degree may be awarded to a student along the way toward a Ph.D. degree, provided Institute and Option requirements are met. The Option requirements for the MS degree are the same as those for the Ph.D. degree except that the MS degree does not require research units, qualifying exam, candidacy exam, and thesis defense. In general, the degree is not conferred before the end of the first year of residence.

MedE Degree of Doctor of Philosophy

- (a) **Admission to Candidacy.** To be recommended for candidacy for the Ph.D. program in Medical Engineering, each student must, in addition to meeting the general Institute requirements of a minimum of 135 units of graduate work, complete all the following requirements:
- Complete 27 units of advanced math courses (i.e., 100 level or above) or ACM 100ab, as arranged with his/her adviser. Math courses that are recommended include, but are not limited to: ACM 100ab, ACM/IDS 101, ACM/IDS 104, ACM 105, ACM 106abc, GE/ESE 118, ACM 201ab, ACM 210ab, ACM/EE/CMS 116, AM 125abc, and Ma 112ab.
 - Complete the three-term seminar sequence, MedE 100abc (1 unit), with a pass grade.
 - Complete MedE 101 (9 units) with a pass grade.
 - Complete the two-term core Medical Engineering course sequence, MedE 201ab (18 units).
 - Complete MedE/BE/Ae 243 (9 units), ChE/BE/MedE 112 (9 Units) or ChE103B (9 Units).
 - Complete EE 111 (9 units).
 - Complete at least 27 units of MedE 291 individual research.
 - Complete minimally an additional 42 units of advanced courses (100 level or higher) in the following 8 topical areas as arranged with the student's adviser. Courses that are recommended but not limited to, include:
 1. Fundamental and Mathematically Oriented Engineering: APh/EE 130 (EM), CDS 101, CDS 110, CDS 140, ChE 103abc, ChE/BE/MedE 188, EE 112, EE/Ma 126 ab, EE 151, EE/CS/IDS 160, EE/CS 161, MS 115, ME 115 ab, ME 118, ME 119ab.
 2. Solid Mechanics: Ae/AM/CE/ME 102abc, Ae 160, AM/ CE 151ab, MS/ME/MedE 116.
 3. Fluid Mechanics: Ae/APh/CE/ME 101abc, Ae 160, Ae/BE 242, ChE/BE/MedE 112.
 4. Biology and Physiology: BE 150, BE 151, BE/Bi 152, BE 159, Bi/Ch 110, Bi/Ch 113, Bi 122, Bi 129, Bi 145, Bi/ CNS/NB 150, Bi/CNS 162, CNS/Bi/Ph/CS/NB 187.
 5. Biomaterials, Biomechanics, and Bioinspired Design: Ae/ BE 242, BE 141, BE159, Ch/ChE 147, ME/MS 260, MS 115, MS/ME/MedE 116.
 6. Medical Photonics and Imaging: APh/EE 130, APh/EE 131, APh/EE 132, Bi/BE 177, Bi/BE 227, ChE 114, EE/ MedE 115, EE 151, EE/APh 180, MedE/EE/BE 168abc, MedE 205.
 7. BioSensing: APh/EE 130, APh/EE 131, APh/EE 132, ChE/ BE/MedE 112, EE/MedE 114ab, EE/MedE 115, EE 151, EE 161, MedE/EE/BE 168abc, MedE 202.
 8. Medical Technologies and Devices: APh 109, APh 114abc, APh/EE 130, APh/EE 131, APh/EE 132, BE/EE/

MedE 189 ab, ChE/BE/MedE 112, ChE 115, E/ME/MedE 105 ab, EE 112, EE/MedE 114 ab, EE/MedE 124, EE 151, EE/APh 180, EE/BE/MedE 185, EE/MedE 187, MedE/EE/BE 168abc, MedE 202, MedE 205.

- All required courses must be taken for grades and passed with a grade of at least a C, except for courses offered only on a pass/fail.
 - Pass an oral qualifying examination, arranged by the Option, on three major subjects before the beginning of the second academic year. Any delay of taking the exam must be pre-approved by the option representative. Each student should consult his/her adviser and/or the option representative to choose the three major subjects. The three subjects of the exam should include (1) engineering math, (2) the major research topical area, and (3) another related topical area. Students should take at least 27 units of advanced courses on each of the three exam subjects. If the student has a subject minor, examination on the minor subject may be included at the request of the discipline offering the minor and with the approval of his/her adviser. Note that the program is designed for the students to have multidisciplinary background.
 - Pass an oral candidacy examination on the subject of the Ph.D. research before the end of the second academic year of residency. The Ph.D. oral candidacy exam is conducted by a committee of minimum four members that is set up by the student and approved by the option representative. Three members must be Caltech professorial faculty affiliated with Medical Engineering. The fourth member may be a Caltech faculty member or an outside professional of similar standing. The committee must include the adviser, but another member of the committee must be selected as chair. The committee chair must be a Caltech Professorial faculty member. This examination will be a test of the candidate's preparation and knowledge to conduct research in his or her specialized doctoral research area.
- (b) **Thesis and Final Examination.** The Ph.D. final thesis defense exam is conducted by a committee that is set up by the student and approved by the option representative. The committee should be made up of minimum of 4 members and at least three of the committee members must be Caltech faculty. The committee must include the adviser, but another member of the committee must be selected as chair. The committee chair must be a Caltech Professorial faculty member. This final examination will be given no less than two weeks after the doctoral thesis has been presented in final form, and before its approval. This examination must be taken at least four weeks before the commencement at which the degree is to be granted. This thesis examination

will be a defense of the doctoral thesis and a test of the candidate's knowledge in his or her specialized doctoral research area.

MedE Subject Minor

A subject minor is not required, but recommended, for the Ph.D. degree in Medical Engineering. However, credits from the subject minor cannot be double-counted for the core program. Students may choose their original engineering disciplines as their minor subjects. Students are not allowed to choose Medical Engineering as a subject minor.

NEUROBIOLOGY (NB)

Aims and Scope of the Graduate Program

Neurobiology—the study of the nervous system—is a highly integrative science. The modern neurobiologist must be conversant with concepts from molecular biology, cell and developmental biology, systems neuroscience, animal behavior, and mathematical modeling. The aim of the graduate program is to expose each student to this breadth of the discipline. To accomplish this, we offer a first-year curriculum with requirements in specified areas, along with a core course that spans many subjects. Students enter neurobiology from many different disciplines, ranging from particle physics to physiology to psychology. Accordingly, each Ph.D. student is paired with a first-year adviser so the course selections can best complement the student's background. In later years, the student's focus is on original research in a chosen specialty. Our goal is that students will graduate with specific research accomplishments and the broad understanding required to chart their subsequent forays in brain science.

NB Admission

Applicants are expected to have studied college-level mathematics, physics, chemistry, and biology. They should also have experience in independent research. Coursework in neurobiology and experience in scientific computing are helpful, but not required. Whenever possible, applicants will be interviewed on campus before final admission decisions are made.

NB Master's Degree

The option does not admit students for work toward the Master's degree. A terminal M.S. may be awarded in exceptional circumstances.

NB Degree of Doctor of Philosophy

First-year adviser

Each incoming student is paired with an academic adviser during

the first year. This mentor will guide the student in course selection and other decisions, taking the student's background into account. Where possible, this adviser will not be one of the prospective rotation supervisors.

Rotations

First-year students carry out three laboratory rotations, each lasting one quarter. At least two of these should be with faculty participating in the option. By June 30 of the first year, students choose a Ph.D. adviser.

Formal Classes

Students take at least 6 quarter courses (54 units) as follows:

1. Bi/CNS/NB 164, Tools of Neurobiology
2. Bi 252, Responsible Conduct of Research
3. One course in molecular, cellular, developmental neurobiology
4. One course in circuits, systems, behavioral biology
5. One course in mathematical methods (depending on the student's background)
6. Two electives

For a list of courses in subject areas 3–5, see the option website. All courses must be taken for a grade unless only offered pass/fail.

Teaching

All students are to serve as teaching assistants for at least three terms.

Admission to Candidacy

To qualify for candidacy, the student must first demonstrate broad competence by passing each of the first-year courses with a grade of B or higher. Failure here can be remedied by successful second-year coursework. By June 30 of the second year, the student must also defend a thesis proposal in an oral exam before a qualifying exam committee of at least three faculty. This exam will also cover general knowledge in the relevant field. With special permission, the oral exam may be retaken once before the end of winter quarter of the third year. Students that do not advance to candidacy by the end of the third year may not continue in the program.

Thesis Advisory Committee

Once admitted to candidacy, the student chooses a Thesis Advisory Committee of at least three faculty. This committee serves as a source of advice independent of the Ph.D. adviser throughout the student's tenure. Each year, before the end of June, the student delivers a written progress report, followed by a meeting with the Thesis Advisory Committee.

Thesis Examination Committee

This committee should consist of a minimum of four voting members, three of whom must be Caltech faculty. The final oral examination covers principally the work of the thesis, and according to Institute regulations must be held at least three weeks before the degree is to be conferred.

PHYSICS (Ph)

Aims and Scope of the Graduate Program

The physics option offers a program leading to the degree of Doctor of Philosophy. This program prepares students for careers in scientific research or research combined with teaching, and so its most important part is independent research. Courses are offered that give a broad treatment of both fundamental physics and specialized physics research topics. These are intended both to help a beginning graduate student prepare for research and to broaden an advanced student's knowledge of physics. Caltech research opportunities include elementary particle physics, nuclear physics, cosmic-ray, gamma-ray, and X-ray astronomy, submillimeter astronomy, condensed-matter physics, atomic/molecular/optical physics, quantum information, applied physics, gravitational physics, cosmology, astrophysics, mathematical physics, biophysics, and theoretical physics.

A Master of Science degree may be awarded upon completion of a program of courses. Students are not normally admitted to work toward the M.S. in physics unless they are also working toward a Ph.D.

Admission

The application submission deadline for Physics is December 15. The admission process follows Institute regulations. Applicants are strongly recommended to submit Graduate Record Examination (GRE) scores for the general test and scores for the Advanced Physics subject test.

Ph Master's Degree

A Master of Science degree in physics will be awarded, upon request, to physics Ph.D. students who have completed the oral and written candidacy examinations. Alternatively, a master's degree will be awarded to any Caltech graduate student in good standing upon satisfactory completion of a program approved by the option representative that fulfills the following requirements:

Ph 125 abc**27 units**

(If this course, or its equivalent, was taken as part of an undergraduate program, it may be replaced by 27 units of any quantum-mechanics-based course.)

Physics electives**81 units**

These must be selected from physics courses numbered 100 and above.

Other electives**27 units**

These must be graduate courses from any option at Caltech.

Substitutions of other graduate courses in place of the above requirements must be approved by the option representative.

In exceptional cases, undergraduate students may receive concurrent B.S./M.S. degrees if the above requirements are met in addition to the relevant B.S. requirements, upon approval from the Physics Graduate Committee, the graduate admissions committee, and the physics executive officer. Such students must produce a detailed petition demonstrating accomplishments that would warrant normal admission to the physics graduate program.

Ph Degree of Doctor of Philosophy

In addition to the general Institute requirements for a Ph.D., the particular requirements for a doctorate in physics include admission to candidacy as described below, writing a thesis that describes the results of independent research, and passing a final oral examination based on this thesis and research. Physics graduate students may exercise the pass/fail option on any and all courses taken.

Advising structure and thesis supervision

An academic adviser is appointed for each student upon admission to the graduate program in physics. The academic adviser will serve as the primary mentor until the student finds a research adviser. Students will meet with their academic adviser to decide on their first-year course schedule, and are encouraged to continue these meetings quarterly until the student finds a research adviser. During the first year of study, students should consult with their academic adviser, the option representative, the executive officer, and/or individual faculty members to select a tentative research group. Once a research adviser is selected students may either replace the originally appointed academic adviser or maintain both a research adviser and academic adviser. At any time, a student may consult with the option representative concerning such matters as advising.

Students should consult with the executive officer to assemble their oral candidacy committee and Thesis Advisory Committee (TAC) by the end of their third year. The TAC is normally constituted from the candidacy examiners, but students may propose variations or changes at any time to the option representative. The TAC chair is normally someone other than the research adviser. The TAC chair will typically also serve as the thesis defense chair, but changes may be made in consultation with the executive officer for physics and the option representative.

The candidacy committee will examine the student's knowledge of his or her chosen field and will consider the appropriateness and scope of the proposed thesis research during the oral candidacy exam. This exam represents the formal commitment of both student and adviser to a research program. After the oral candidacy exam, students will hold annual meetings with the TAC. The TAC will review the research progress and provide feedback and guidance towards completion of the degree.

The TAC, research, and/or academic advisers provide the majority of mentoring to the student. In addition, the option representative and other members of the faculty are always available to provide advice and mentoring on any aspect of research, progress toward the Ph.D., future careers, and other aspects of life in graduate school.

Basic Physics Requirement

Physics students must demonstrate proficiency in all areas of basic physics, including classical mechanics (including continuum mechanics), electricity and magnetism, quantum mechanics, statistical physics, optics, basic mathematical methods of physics, and the physical origin of everyday phenomena. A solid understanding of these fundamental areas of physics is considered essential and proficiency will be tested by two written candidacy examinations.

No specific course work is required for the basic physics requirement, but some students may benefit from taking several of the basic graduate courses, such as Ph 106, Ph 125, and Ph 127. A syllabus describing the exam contents will be available, and students are encouraged to study independently for the exams, rather than taking a heavy load of basic physics courses. In addition, the class Ph 201 will provide additional problem solving training that matches the basic physics requirement.

The written exams are typically offered in July and in October, and the two separate exams may be taken at different times. This flexible scheduling of the written exams allows students to prepare for the exams while simultaneously learning about research areas, either through advanced courses, reading courses, or participation in a research group. The exams can be attempted up to three times and must be successfully completed by the end of the second year of study.

Advanced Physics Requirement

In addition to demonstrating a proficiency in basic physics, students must also establish a broad understanding of modern physics through study in six graduate courses. The courses must be spread over at least three of the following four areas of advanced physics:

1. Physics of elementary particles and fields
Nuclear physics, high-energy physics, string theory
2. Quantum information and matter
Atomic/molecular/optical physics, condensed-matter physics, quantum information
3. Physics of the universe
Gravitational physics, astrophysics, cosmology
4. Interdisciplinary physics
e.g., Biophysics, applied physics, chemical physics, mathematical physics, experimental physics

Each area is meant to be covered by the equivalent of a one-term course, and a list of example courses for each of the areas can be found at the physics option website. Other courses may be substituted with permission of the physics option representative.

Oral Candidacy Exam

This exam is primarily a test of the candidate's suitability for research in his or her chosen field. The professor with whom the student plans to do research will be a member of the exam committee, and normally the student will have already begun research (Ph 172) on a definite topic with that professor. The examination will cover the student's research work and its relation to the general field of specialization. Before being allowed to take this exam, a student must have satisfied all the other requirements for admission to candidacy. The oral candidacy exam should be completed by the end of the third year (twelve term) of graduate residence.

Admission to Candidacy

To be recommended for Ph.D. candidacy, a student must pass two terms of Physics Seminar (Ph 242), satisfy the Basic Physics Requirement by passing the written candidacy examinations, satisfy the Advanced Physics requirements, and pass the Oral Candidacy Examination. These requirements are designed to ensure that students have an adequate preparation in the basic tools of physics, as well as a broad general knowledge of advanced physics.

Research Requirements

There are no specific research requirements, but in general a substantial effort is required to master the techniques in a given field and carry out a significant piece of original research. Students are strongly advised to start doing part-time research as soon as possible by taking reading and research units (Ph 171–172) in parallel with formal coursework.

Thesis and Final Examination

A final oral examination will be given not less than two weeks after the thesis has been presented in final form. This examination will cover the thesis topic and its relation to the general body of knowledge of physics. The candidate is responsible for completing the thesis early enough to allow the fulfillment of all division and Institute requirements, with due regard for possible scheduling conflicts.

Degree progress timeline

The following timeline is required for satisfactory degree progress:

1. Ph 242 should be taken by all students in their first year of graduate study.
2. The written candidacy exams should be attempted by the end of a student's first year of graduate residence, and be passed by the end of the second year.
3. The Advanced Physics requirement should be completed by the end of the second year of graduate residence, but may be extended into the third year depending on the availability of specific courses.
4. The oral candidacy exam must be completed by the end of the third year (twelfth term) of graduate residence.

The Minor

A minor is not required, but a student may elect to pursue a minor in another option.

Language Requirements

There are no language requirements for a Ph.D. in physics.

Ph Subject Minor

Students desiring a subject minor in physics should discuss their proposed program with the chair of the Physics Graduate Committee. Forty-five units from physics courses with numbers over 100 must be taken for the subject minor, excluding Ph 129 and any specific courses in physics required for the student's major program. An oral exam may be required by the Physics Graduate Committee. This exam will include both academic topics and topics on current physics research areas.

QUANTUM SCIENCE AND ENGINEERING (QSE)

Quantum science and engineering (QSE) may be pursued as a subject minor by graduate students who are pursuing Ph.D. degrees in any option. The QSE minor is intended to supplement one of Caltech's graduate degrees and is designed for students who wish to broaden their knowledge of QSE beyond their major

field of study. The QSE minor is also intended to recognize graduate students' interest in and dedication to QSE as demonstrated by the successful completion of a program of study in the field. Completion of the QSE minor program of study will be recognized on the Ph.D. diploma by the statement, "...and by additional studies constituting a minor in Quantum Science and Engineering."

Requirements

To receive the QSE minor, graduate students must fulfill the following requirements:

- 18 units (two terms) from the following list: APh/Ph 138ab
- 18 units (two terms) from the following list: Ph 137ab, Ph/CS 219abc, CS/Ph 120, Ph/APh 223ab, APh 150 (special topics class when topic is relevant to QSE, in consultation with the oversight committee), Ph177 (relevant QSE topic must be chosen in consultation with oversight committee). Other courses relevant to QSE can be included in consultation with the oversight committee.

All courses to be applied toward the QSE minor requirements must be taken on a graded basis, and students must obtain a grade of B- or higher in all courses. At least 18 units of courses that are used to satisfy the QSE minor cannot be used to satisfy course requirements in the major options unless absolutely required by the option. Courses taken as part of the QSE minor are counted toward the total number of units required for the completion of the Ph.D. degree.

QSE Minor Administration

The QSE minor is administered by an oversight committee consisting of faculty members reporting to the chair of the engineering and applied science division. In consultation with their advisers and, if needed, with the QSE Oversight Committee, students formulate a program of approved courses individually tailored to each student's background and needs, with the objective that the student achieve a level of competence in specific subjects relevant to QSE. Students must petition the QSE Oversight Committee for approval of their program of study. Upon completion of the program of study, the QSE Oversight Committee will verify that the QSE minor requirements have been fulfilled.

SOCIAL AND DECISION NEUROSCIENCE (SDN)

Aims and Scope of the Graduate Program

The Caltech Ph.D. program in social and decision neuroscience (SDN) prepares students to do research on the neurocomputational basis of decision-making and social interactions. Research in this area requires training in computational modeling, statisti-

cal methods, systems neuroscience, neural measuring methods such as fMRI, EEG or single unit recordings, as well as adequate understanding of related methods and results from the social sciences. Students' career paths include faculty jobs in Neuroscience, Psychology or Marketing; faculty jobs in Economics, Political Science or Finance programs; and industry positions in the technology, data science, finance, and neurotechnology sectors.

SDN Master's Degree

Students are not admitted to work towards the master's degree. The master's degree might be awarded to an SDN student under exceptional circumstances. In order to be eligible for a master's degree, students must complete at least 54 units of the courses required for the Ph.D. with a passing grade, as well as a minimum of 81 additional units of graduate work.

Admission

The program seeks to recruit top students interested in the neurocomputational basis of decision-making and social interactions. Ideal applicants will have very strong quantitative backgrounds, regardless of their undergraduate major. Previous exposure to neuroscience, psychology or economics is useful but not required. Students are required to submit Graduate Record Examination (GRE) verbal and quantitative scores, as well as information regarding their research experience and interests. Students who are not native English speakers are also required to submit evidence of English proficiency, such as the TOEFL, the PTE, or the IELTS.

Course Requirements

Students are required to complete 81 units of graduate coursework related to Social and Decision Neuroscience by the end of their second year, with a grade of B or higher in each class. The coursework must satisfy the following requirements. Students should take a minimum of 54 units during their first year and 27 units during their second year. First year coursework must include CNS/ Psy/Bi 102 ab (Brains, Minds, and Society) and two courses in statistics, econometrics or machine learning. Students are also required to take Bi/CNS/NB/Psy 150 (Introduction to Neuroscience), a graduate course in behavioral economics, and two additional upper-undergraduate or graduate courses (i.e., numbered 100 or higher) in economics, political science or finance.

Lab Rotations

Students are required to complete three quarters of lab rotations during their first year. These rotations should include work in two different labs, for a minimum of one quarter each. Lab rotation plans need to be approved by the option representative by the end of the second week of the Fall quarter. Students must sign-

up for 18 units of CNS 280 (Research in Computation and Neural Systems) or SS 300 (Research in the Social Science) for each quarter of lab rotations. Students are expected to become full members of a research group by the end of the Spring quarter of their first year. The faculty member leading that lab becomes the student's main adviser.

General Knowledge Exam

Students are required to take a written General Knowledge Exam in Social and Decision Neuroscience. The exam is offered during Spring quarter of the second year and students must pass it with a grade of at least 80%. A list of topics and references associated with the exam can be obtained from the option representative.

Other Requirements

Students must satisfy the following additional requirements.

1. They must enroll in Psy 283abc (Graduate Proseminar in Social and Decision Neuroscience) every quarter, from their first to their last quarter in residence. This weekly seminar provides training in academic skills such as writing, presenting, reviewing, and career strategy, as well as breadth of knowledge in Social and Decision Neuroscience.
2. Students must attend four social science seminars in economics, finance or political science every quarter, from their first to their last quarter in residence.
3. Students are also required to complete Bi 252 (Responsible Conduct of Research) during their first year.
4. Students must attend a conference and submit a grant proposal during their second year.
5. Starting their second year, students are expected to TA a minimum of three quarters total during their graduate career.
6. Starting the third year, students must present a poster or give a talk at a conference every academic year.
7. Students must submit yearly progress reports to the SDN option representative by the last day of classes of the Spring quarter, starting on their first year. A template for the report can be obtained from the option representative. These reports will be reviewed by the entire SDN faculty and granted one of three outcomes: approval, conditional approval, or program termination. Students may receive at most one conditional approval of their yearly report during their time in the Ph.D. program.

Candidacy Requirement

Students must form a thesis committee and defend their thesis proposal to the committee. Students must pass this candidacy exam by the last day of classes of their third year. A thesis commit-

tee must have four members subject to the following constraints: at least one should be a neuroscience faculty member, at least one should be a non-neuro social science faculty member, and there should be at most one faculty member from another institution. The main adviser cannot serve as the chair of the thesis committee.

Thesis and Final Examination

The candidate is expected to complete and successfully defend their thesis by the last day of classes of the Spring quarter of their fifth year. Extensions to an additional sixth year will be considered only at the candidacy exam stage and, if necessary, for the proposed research plan.

The time of the defense should be determined in consultation with the main adviser, the thesis committee and, if necessary, the option representative. Students must submit a written copy of their dissertation to the thesis committee at least two weeks prior to the thesis defense date.

SOCIAL SCIENCE (SS)

Aims and Scope of the Graduate Program

The Caltech Ph.D. program in social science prepares students for an academic career in economics and political science. It is designed to produce scholars who are well grounded in the theoretical perspectives, the quantitative techniques, and the experimental methods of economics and political science.

SS Master's Degree

Students who are enrolled in the Social Science Ph.D. program may earn a M.S. degree after successful completion of 36 units of course work, approved at least with a B grade, in addition to completing the coursework required for the first year of the Ph.D. program.

Admission

Admission to the Caltech Ph.D. program is based on prospective students' academic records, research interests, GRE scores, and letters of recommendation. Students who are not native English speakers are also required to submit scores from the TOEFL exam.

Course Program

First year. The first-year curriculum consists of the following three-quarter course sequences: Analytical Foundations in Social Science (SS 201abc); Political Theory (SS 202abc); Foundations of Economics (SS 205abc) and Econometrics (SS 222abc). Each class must be completed with a grade of B or better.

At the end of the first year, the faculty will review the overall class performance of each first-year student, and assess the

student's ability for clear self-expression in both oral and written English. A positive assessment of class performance is required for a student to remain in good standing in the program. If class performance is judged unsatisfactory by the faculty, they may terminate the student from the program. In case of language deficiencies, the student is required to take and pass a remedial English class, SS 299, during the summer quarter.

Before the start of the second year, students are required to take a written preliminary examination, which has four components, each corresponding to one of the first-year course sequences (SS 201, SS 202, SS 205, and SS 222). The grades given are Honors, Pass, and Fail. Students must achieve at least a Pass in all four parts. The Social Science faculty will review the student's performance on the exam, and progress, to date. If it is not satisfactory, they may terminate the student from the program by the beginning of the second year.

Second year. Second-year courses provide additional training in various subfields of the social sciences.

In the fall quarter, all second-year students are required to enroll in SS 224 and at least 27 additional units of advanced Social Science courses. In the winter quarter, all second-year students are required to enroll in at least 36 units of advanced Social Science courses. In the spring quarter, second year students must enroll in at least 27 units of advanced Social Science courses (three typical courses) and enroll in Research in Social Science (SS 300) to work on their second-year paper, for the units remaining to reach 36 units.

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Appropriate courses in other options, such as mathematics and computer science, can be substituted for advanced Social Science classes, with the permission of the HSS division's Option Representative. Two classes, SS 281 and SS 300, are taken on a pass/fail basis. All other classes offered for grades must be taken for grades, and completed with a grade of B or better. Students may take independent reading and study courses, but during the second year such courses do not count toward the above requirements.

Students can tailor their second-year curriculum to their specific research interests, but are expected to include at least two second-year course sequences. Such course sequences include Foundations of Political Economy (SS 210abc), Advanced Economic Theory (SS 211abc), Financial Economics (SS 213abc), Topics in Theoretical and Applied Econometrics (SS 223abc), Applied Empirical Methods in the Social Sciences (SS 228abc), Theoretical and Quantitative Dimensions of Historical Development (SS 229abc), American and Comparative Politics (SS 231abc), and Experimental Methods of Political Economy (SS 260). Students may partially fulfill the second-year sequence requirement by tak-

ing a sequence of courses in mathematics, such as Ma 108abc, Ma 110abc, Ma 144ab, or Ec 181ab.

Third year. Beginning in their third year, and in all subsequent years, all students must enroll in the 3-unit graduate student pro-seminar (SS 282abc) every quarter. Every student must make a presentation in this class at least once a year. Students in the third year may also enroll in additional courses, with the approval of their adviser. Third year students are required to take SS 281 in the fall quarter. In each quarter, third year students should enroll in Research in Social Science (SS 300) for the units remaining to reach 36 units.

Fourth and fifth years. Students need to register for 33 units of SS 300 and 3 units of the graduate student pro-seminar (SS 282abc).

Progress in the program, and advancement to candidacy

In addition to the coursework and examinations described above, students must enroll in at least 36 units every quarter, including summer (SS 300) and complete the following requirements.

By May 1 of the second year, each second-year student must submit an outline describing a planned paper to their paper adviser, their second reader, and the Option Representative. The second-year paper can be co-authored. If the co-author is another graduate student, only one of the students on the joint project can use the paper to fulfill the requirement. The person using the paper for fulfilling the requirement is expected to do most of the actual writing of the paper that is submitted. The final paper is due on September 15. If the paper adviser and the second reader both find that a student's second-year paper is satisfactory, the student advances to the third year. If they do not, the social science faculty as a whole will review the student's paper. If they decide that the paper is not satisfactory, they may terminate the student from the program. At the end of the second year, the social science faculty will also meet and assess each second-year student's ability for clear self-expression in both oral and written English. In case of language deficiencies, the student is required to take and pass a remedial English class, SS 299, during the summer quarter. Also, starting their second year, students are expected to TA a minimum of three quarters total during their graduate career.

Third-year students must write a research paper and present it to the faculty at the end of spring quarter. The third-year paper cannot be co-authored, but should be worked on in consultation with and under the direction of the student's primary adviser. The Option Representative will appoint a second third-year paper reader, who must be a member of the Social Sciences profes-

rial faculty. The adviser and second reader will monitor progress and advise the student on the third-year paper. The paper and the presentation must demonstrate to the faculty that the student is capable of undertaking original research and presenting it to a scholarly audience.

After completion of the third-year paper presentation, the social science faculty evaluates the student's overall performance and research potential. This review is based primarily upon the third-year paper, but the faculty also verifies that the student has satisfactorily completed all previous requirements.

If this evaluation is favorable, the student is admitted to candidacy for the Ph.D. If the faculty evaluation is unfavorable, the student may be terminated from the program.

Organization of Thesis Committee

By October 1 of the third year, each student selects a primary adviser. The adviser must be a professorial member of the social science faculty at Caltech. It is possible to change advisers, in consultation with the Option Representative, if a student's research interests change. Students, in consultation with their adviser, must select two additional thesis committee members after the student has advanced to candidacy (normally by the beginning of their fourth year). After a student advances to candidacy, the division chairperson, in consultation with the Option Representative, shall select a fourth member of the committee with an eye to representing the diverse interests of the social science faculty. One of the four members of the thesis committee may be Emeritus faculty, research faculty, or an external scholar, with the approval of the Option Representative and the Dean of Graduate Studies. The chair of the thesis committee must be someone other than the primary adviser, and will be appointed by the Social Science Option Representative in consultation with the primary adviser. The thesis committee will also serve as the examination committee at the thesis defense.

SS Degree of Doctor of Philosophy

By November 1 of their fourth year, students must complete a dissertation prospectus that outlines the proposed dissertation work, and presents a tentative schedule detailing when the components of the dissertation are to be completed. The prospectus must clearly identify a project, or dissertation components, that should culminate in a job market paper at the beginning of the student's fifth year (August before the start of the fifth year, in the case of students who seek a position in political science). The prospectus must be approved by the thesis committee by November 1, and the status communicated by the principal adviser to the Option Representative.

By May 1 of the fourth year, the student is required to convene a

thesis prospectus seminar with their thesis committee. In this seminar, the student is to report on the current status of their dissertation research and outline a plan and timeline for completing it. The seminar must be based on the student's planned job market paper, and a draft of this paper must accompany the proposal. The student and the thesis committee should reach a clear, mutual understanding as to what additional work needs to be done to complete and to successfully defend their dissertation.

After the dissertation is completed, the student, in consultation with their adviser, must schedule an oral thesis examination to defend their dissertation. The student must provide a written copy of their dissertation to the Option Representative and all members of the examination committee, and complete the examination notification in Regis, not less than two weeks prior to the thesis examination date. The dissertation is expected to represent publishable, original research.