

Competence will be demonstrated in either of two ways. The applicant may complete an appropriate Caltech course with a grade no lower than C. Alternatively, a student supplying evidence of having done equivalent work elsewhere may demonstrate competence through an oral examination.

Separate examinations will be required for each area.

- Oral candidacy examination. The student will prepare a brief presentation on a topic agreed upon by the student and the research adviser for the student's proposed thesis; normally the topic will be the projected research. The candidacy examination will be based upon the student's background in applied physics and its relation to this presentation. The oral examination will be given only after the student has demonstrated competence in the five areas, and must be completed before the close of the student's second year of residence. If the examination is not passed, it may be retaken if the Candidacy committee so recommends.
- Competence in research must be demonstrated as follows: The student must have a doctoral thesis adviser and must have completed 18 units of research with this adviser no later than the beginning of the student's third year of residence.

The Minor. By its nature, applied physics spans a variety of disciplines, and the major requirements reflect this. A minor is *not* required of students majoring in applied physics. Students are, however, encouraged to take advanced courses appropriate to their particular interests.

Thesis and Final Examination. The candidate is required to take a final oral examination covering his or her doctoral thesis and its significance and relation to his or her major field. This final examination will be given not less than two weeks after the doctoral thesis has been presented in final form, and prior to its approval. This examination must be taken at least four weeks before the commencement at which the degree is to be granted.

Subject Minor

Graduate students electing a subject minor in applied physics must complete 54 units of graduate courses in applied physics. The courses may be selected from any of the applied physics courses with numbers *greater than* 100, excluding APh 110 and APh 200.

The student's proposed program must be approved by the Applied Physics Graduate Studies Committee. The committee will examine the course program to determine which of the following areas of interest in applied physics it includes:

Group A: Ae/APh/CE/ME 101, APh 156

Group B: APh 105, APh 114, APh/EE 183, or Ph 136

Group C: APh/EE 130, APh/EE 131, APh/EE 132, APh 190

It is recommended that the program include courses from more than one of the above areas.

The Applied Physics Graduate Studies Committee may recommend an oral examination based upon its evaluation of the course program. When the program includes more than one of the above areas of interest, then an oral examination may not be required.

Astrophysics

Aims and Scope of the Graduate Program

Modern astronomy—certainly as practiced at Caltech—is essentially astrophysics. With the goal of understanding the physical processes that govern the universe, its constituents, and their evolution, astronomy uses the apparatus and methodology of physics to gather and interpret data. In what follows, we use the terms astronomy and astrophysics interchangeably.

The primary aim of the graduate astrophysics program at Caltech is to prepare students for creative and productive careers in astrophysical research. 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.

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. All applicants, including those from foreign countries, are requested to submit Graduate Record Examination scores for verbal and quantitative aptitude tests and the advanced test in physics.

Placement Examination

Each student admitted to work for an advanced degree in astrophysics is required to take the placement examination in physics (see Placement Examinations, page 321) covering material equivalent to Ph 106, Ph 125, and Ph 129. This examination will test whether the student's background is sufficiently strong to permit advanced study in astrophysics. If it is not, students will be required to pass the appropriate courses.

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 department. 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.

Degree of Doctor of Philosophy

Astrophysics Program. The student's proposed overall program of study must be approved by the department 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. Observational astronomy students should also take Ay 122. Also required are research and reading projects. Credit for this work will be given under courses Ay 142 and Ay 143.

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 by the option representative or executive officer. Cross-listed courses (e.g., Ph/Ay) in general do not count towards the physics units requirement, unless specifically allowed by prior consultation between the student, the instructor, and the student's option representative. This requirement may be reduced on written approval of the department for students who take substantial numbers of units in Ph 106, Ph 125 or APh 125, and Ph 129. Students in radio astronomy may substitute an advanced course in electrical engineering or applied mechanics for up to nine units of the required 36 units of physics. Theoretical astrophysics students should include at least 54 units of physics courses in their programs. Students in planetary physics may substitute appropriate advanced courses in geophysics and geochemistry. All the above courses must be passed with a grade of C or better, or a P upon prior written permission from the option representative to take the course pass/fail.

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, required of all students in their second year and all subsequent years.

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 with a grade of B or better, or by special examination, Ay 121, Ay 123, Ay 124, Ay 125, Ay 126, and Ay 127; and also Ay 122 for observational astronomy students;
- 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 (at least one term as a GTA);
- fulfill the language requirement if applicable (see above); and
- be accepted for thesis research by a member of the faculty, or, by special arrangement, a staff member of the Observatories of the Carnegie Institution of Washington.

In November of their second year, all students are required to take a general oral candidacy examination. Students will be examined on the substance and status, 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 receive more than two C (or lower) grades in the Ay 120 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 second term 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. Under no circumstances will students be permitted to continue beyond the third year without successful completion of all candidacy requirements.

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 Counseling Center and the Ombuds Office.

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. Only in rare circumstances will permission be granted to continue in a sixth year. Such permission requires a written petition to the executive officer.

Typical timeline:

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

Year 2: November—general oral candidacy examination. Research projects; select thesis and adviser. Fulfill teaching requirement. Complete 36 units of physics (54 for theorists); 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.

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.

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

Aims and Scope of the Graduate Program

An integrated approach to graduate study in biochemistry and molecular biophysics has been organized primarily by the Division of Biology and the Division of Chemistry and Chemical Engineering. The curriculum is designed to provide a broad background in protein biochemistry, structural biology, and molecular genetics, in addition to an appropriate depth of knowledge in the field selected for the Ph.D. thesis research.

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. All applicants for admission, including those from foreign countries, are required to submit the verbal, quantitative, and analytical scores for the Graduate Record Examination and are also strongly urged to submit the results of an advanced test in a scientific field. 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.

Master's Degree

Students are not normally admitted to 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.

Degree of Doctor of Philosophy

The Option Graduate Study Committee will counsel and oversee the student's progress upon admission to the graduate program. In the first year of graduate study, the course requirement consists of a sequence of three core courses covering topics in structural