
Physics

Professor Howard Georgi, Director of Undergraduate Studies

The concentration in Physics, administered by the Department of Physics, serves a variety of goals and interests. Many concentrators seek an understanding of the subtle, profound, and fundamental laws—relativity, quantum mechanics, and the basic force laws—that govern the behavior of all matter. Often these studies involve the smallest units of matter: molecules, atoms, nuclei, and subnuclear particles. A major interest of other Physics concentrators is the exploration and explanation of the diverse properties to which these laws give rise in macroscopic systems such as fluids and solids. Still others study aspects of more complex systems like oceans and atmospheres, stars, and living matter.

A concentration in Physics provides a foundation for subsequent professional work in physics, and also for work in astronomy, biophysics, chemical physics, engineering and applied physics, earth and planetary sciences, geology, astrophysics, and the history and philosophy of science. Less obviously perhaps, the intellectual attitudes in physics—blending imagination, prediction, observation, and deduction—provide an excellent base for subsequent graduate work in professional schools of medicine, education, law, business, and public administration.

It should be emphasized that since all the physical sciences require basic training in physics and mathematics, an early choice of concentration need not be a final one. It is quite possible to design a program that will permit a change in concentration at the end of the sophomore year or even later. For example, a student who has satisfied most of the requirements for a concentration in astronomy probably has also satisfied most of the physics requirements as well, and vice versa.

The department tries to provide the essential content of undergraduate physics in concentrated form, leaving students sufficient time to develop interests through related courses offered by other science departments, to pursue more advanced and specialized aspects of physics through graduate-level courses and independent study or laboratory work, or to take advantage of the opportunities Harvard provides for a broad liberal arts education. By keeping the number of required courses small (twelve half-courses in Physics and related fields; 13 to 15 half-courses for honors candidates) and matching advisers to students, individual students are able to construct programs suited to their interests and career plans.

There are two basic avenues for entering Physics or one of the other concentrations in which it plays a major role. Most students commence their studies with the Physics 15a, 15b, 15c sequence of courses. This avenue is recommended for those who have had a normal high school course in physics or no previous physics at all. Students who enter with the appropriate Advanced Placement background may begin their study of physics with Physics 16 instead of Physics 15a. The Physics 15a, 15b, 15c courses are taught both terms, so that those students who wish to begin Physics in the second term may do so.

The Physics Department does not require that undergraduates take tutorials, i.e., individual instruction. This is not because independent study is considered unimportant, but rather because it has been deemed more important to keep the concentration requirements flexible enough to satisfy the differing goals of a great variety of students. There are programs that enable students to examine special fields and topics in some detail under the guidance of experts. We offer the following optional tutorial and independent study programs: (1) Physics 91r: individual study of material not covered in regular courses, supervised by a member of the department; (2) Physics 90r: individual research under the supervision of a faculty member interested in the field. The exact form of the project depends on the student's experience and interest, the nature of the particular field, and the availability of necessary facilities and funds. Concentrators desiring to write a senior thesis may do so under this program.

Physics does offer joint concentrations with other programs (e.g., Physics and Mathematics, Physics and Astronomy, and Physics and History and Science) with the provision that the student's Plan of Study be approved by the Director or Assistant Director of Undergraduate Studies and that the student meet the requirements for honors eligibility in both concentrations. Within the Physics Department we provide an Applied Physics option, which emphasizes courses covering physical applications (see **Requirements for the Applied Physics Option**). We also offer a biophysics option, which allows a limited substitution of biology courses for physics-related courses (see **Requirements for Biophysics Option**). Finally, we offer a Physics and Teaching option, which provides both preparation in physics and eligibility for the teaching certificate required for public school teaching in many states (see **Requirements for the Physics and Teaching Option**). See also the concentration in Chemistry and Physics. We also collaborate in offering many of the courses required for concentrations in Astronomy and in applied sciences.

No thesis or General Examination is required for a degree with honors in Physics.

For information on the secondary field in Physics, please see page 367 of this *Handbook* or the secondary fields website (www.secondaryfields.fas.harvard.edu/Physics/program-desc-physics.htm).

OPTIONS

Physics
 Physics with Applied Physics emphasis
 Physics with Biophysics emphasis
 Physics and Teaching

REQUIREMENTS

Basic Requirements: 12 half-courses

1. *Required courses:*
 - a. Physics 15a, 15b, 15c. Students who have demonstrated sufficiently strong preparation in physics and mathematics may take Physics 16 in place of Physics 15a (See item 5f).
 - b. Physics 143a.
 - c. Mathematics at least through Mathematics 21a and 21b; Mathematics 23a and 23b; Mathematics 25a and 25b; or Applied Mathematics 21a and 21b. While not required, taking one or more additional mathematics courses is strongly recommended. Students should give special consideration to the courses listed in item 1c of the **Requirements for Honors Eligibility**.
 - d. Two additional half-courses in Physics.
 - e. Additional half-courses in Physics, or a related field, to complete the requirement of twelve half-courses (see item 5d).
2. *Tutorial:* None.
3. *Thesis:* None.
4. *General Examination:* None.
5. *Other information:*
 - a. *Courses counted as Physics courses include:*
 - i. Applied Mathematics 201, 202.
 - ii. Applied Physics (all courses).
 - iii. Astronomy 145, 150, 191.
 - iv. Chemistry 160, 161, 242.

- v. Engineering Sciences 120, 123, 125, 128, 151, 154, 173, 181, 190, and any 200-level course containing a significant amount of physics. See the Director or Assistant Director of Undergraduate Studies for approval.
- vi. Summer School PHYS S-123ab, an eight-week course that counts as a half-course.
- b. *Related courses include:*
 - i. Applied Mathematics.
 - ii. Applied Physics.
 - iii. Astronomy (except Astronomy 1 and 2).
 - iv. Biophysics 164r.
 - v. Chemistry.
 - vi. Computer Science.
 - vii. Earth and Planetary Sciences 108, 121, 131, 132, 133, 140, 161, 166, 167, 200, 201, 236, 243, 260, 263, 264.
 - viii. Engineering Sciences.
 - ix. Mathematics at the 100 or 200 level.
 - x. Statistics (except Statistics 100, 101, 102, and 104).
- c. Neither Physical Sciences 2 or 3, Physics 11a or 11b, nor any Core course may be counted for concentration.
- d. Physics 90r and 91r can be used, together or individually, to satisfy at most two of the required courses.
- e. *Pass/Fail:* Two half-courses may be taken Pass/Fail. These may not include Physics 15a, 15b, 15c or 16.
- f. Students with exceptional preparation in physics may wish to discuss the possibility of substituting more advanced courses for some of these introductory courses. Written permission of the Director of Undergraduate Studies is required if this is done.

Requirements for Honors Eligibility: 13–15 half-courses

1. *Required courses:*
 - a–b. Same as **Basic Requirements**.
 - c. Mathematics courses including at least two half-courses above the level of Mathematics 21a, 21b; Mathematics 23a, 23b; Mathematics 25a, 25b; or Applied Mathematics 21a, 21b. Among those courses to choose from, consider especially Applied Mathematics 105a or Mathematics 113; Applied Mathematics 105b, Mathematics 112, or Mathematics 134; Mathematics 115; and Mathematics 119.
 - d. The laboratory course Physics 191r (see item 5h).
 - e. Three additional half-courses in Physics that should normally include Physics 143b and 181.
 - f. Additional half-courses in Physics, or a related field, to complete the requirement of 13 to 15 half-courses (see items 5f–g).
2. *Tutorial:* None.
3. *Thesis:* Optional: Students wishing to submit a thesis should obtain a copy of the Departmental regulations from the Assistant Director of Undergraduate Studies Office, Lyman 233.
4. *General Examination:* None.
5. *Other information:*
 - a–d. Same as **Basic Requirements**.

- e. *Pass/Fail*: Two half-courses may be taken Pass/Fail. These may not include Physics 15a, 15b, 15c, 16 or 191r.
- f. The number of courses required for honors candidates is reduced by one half-course for each of the half-courses, Mathematics 1a and/or Mathematics 1b, which a student is permitted to skip by virtue of his or her performance on the appropriate Advanced Placement Examination.
- g. With the exception of transfer students, the total number of half-courses actually taken at Harvard in this concentration cannot drop below a minimum of 13 chosen from the courses listed as required (items 1a–f).
- h. Astronomy 191 may be substituted for Physics 191r with the permission of the Director of Undergraduate Studies by students who have demonstrated a serious academic interest in astrophysics by completing a number of appropriate courses in astronomy and astrophysics. Honors candidates are advised to obtain additional experience in experimental physics by assisting in research through Physics 90r, or by working during the summer in an industrial, university, or government laboratory.

Requirements for the Applied Physics Option 13-15 half-courses

1. *Required courses*:
 - a–b. Same as **Basic Requirements**.
 - c. Mathematics courses must include at least one half course above the level of Mathematics 21a and 21b; Mathematics 23a and 23b; Mathematics 25a and 25b; or Applied Mathematics 21a and 21b. Among courses to choose from, consider especially Applied Mathematics 105a, 105b, 111, 120.
 - d. The laboratory course Physics 191r.
 - e. Physics 175: Quantum Electronics and Modern Optics and Engineering Sciences 173: Electronic and Photonic Semiconductor Devices.
 - f. Additional half-courses in physics or a related field, to complete the requirement of 13 to 15 half-courses.
2. *Tutorial*: None.
3. *Thesis*: Optional.
4. *General Examination*: None.
5. *Other information*:
 - a–d. Same as **Basic Requirements**.
 - e–g. Same as **Requirements for Honors Eligibility**.
 - h. Applied Physics 190 (Materials Physics) or Applied Physics 195 (Solid State Physics), and Engineering Sciences 123 (Fluid Mechanics) are highly recommended.
 - i. Students taking this option are advised to take Physics 123 and to obtain additional experience in experimental physics by taking Physics 90r or Engineering Sciences 91r, and/or by working during the summer in an industrial, university or government laboratory.

Requirements for the Biophysics Option 13-15 half-courses

1. *Required courses:*
 - a–c. Same as **Basic Requirements**.
 - d. Two half-courses of Physics 90r under the supervision of a member of the Committee on Higher Degrees in Biophysics or another biophysicist approved by the Director of Undergraduate Studies in Physics.
 - e. Two additional half-courses in physics.
 - f. Additional half-courses in physics or a related field, to complete the requirement of 13 to 15 half-courses.
2. *Tutorial:* None.
3. *Thesis:* Optional.
4. *General Examination:* None.
5. *Other information:*
 - a–e. Same as **Basic Requirements**.
 - f–g. Same as **Requirements for Honors Eligibility**.
 - h. In fulfilling the requirement in item 1f, a student may take up to two half-courses from the following: Life Sciences 1a, 1b; MCB 52, 54, 56, and 80 (formerly Biological Sciences 52, 54, 56, 80); and Biophysics courses numbered above 100
 - i. Students choosing this option are advised to take Physics 181 or Chemistry 161, and Physics 140 and/or Physics 136 in completing the requirements for honors eligibility in Physics. They should also take steps to acquire a basic knowledge of organic chemistry in its relation to biochemistry, although they need not enroll in Chemistry 20.

Requirements for the Physics and Teaching Option

This option is offered by the Department of Physics to encourage well-prepared students with a degree in physics to enter secondary school teaching in the much-needed areas of physics, physics and chemistry, physics and general science, and physics and mathematics. Students who choose this option will complete the Undergraduate Teacher Education Program (UTEP, see page 47 for more information) as part of this program. They will thereby obtain eligibility for the teaching certificate required for public school teaching by about thirty states, including Massachusetts.

Note: Those who plan to teach only in independent schools will not need a teaching certificate, and hence do not need to take this program. However, they too may wish to take UTEP courses to enhance their career preparation. (Basic physics concentrators who plan public school teaching after graduation should inquire at the Graduate School of Education about the possibility of admission to UTEP, independent of this option.)

Under this option, there is a variety of choices depending upon the intended subject area of school teaching. *But note that in each case Advanced Placement credit is acceptable in lieu of the corresponding required course work.*

Physics with Teacher Certification in Physics

1. *Required courses in Physics and related subjects (13 half-courses):*
 - a. Physics 15a, 15b, 15c or Physics 16, 15b, 15c as in the **Basic Requirements**.
 - b. Physics 143a and 181.
 - c. Mathematics at least through Mathematics 21a, 21b (or Mathematics 23a, 23b or Mathematics 25a, 25b).

- d. One half-course chosen from Life Sciences 1a, Physical Sciences 1, or Chemistry 40. See item 6e.
 - e. One half-course in a related subject (see item 6b).
 - f. Additional courses in physics or related subjects (see item 6b), to make a minimum total of 13 half-courses.
2. *Tutorial*: None.
 3. *Thesis*: None.
 4. *General Examination*: None.
 5. *UTEP*: The course and teaching requirements of the Undergraduate Teaching Education program **must** be completed before graduating under this program. These consist of four half-courses, including Student Teaching, as well as (noncourse) fieldwork, as described in detail in the booklet entitled *UTEP Courses that Form Part of the Requirements for the Physics and Teaching Options*.

Normally, it should be possible to meet the UTEP requirements and to also fulfill the requirements in item 1 above during a four-year period as an undergraduate; but it is also possible to graduate under the physics program without the Teaching Certification option and to complete the teacher preparation subsequently under UTEP as a post-baccalaureate student. To obtain more information on this option, contact the UTEP administrator (see item 6f).
 6. *Other information*:
 - a. Courses counted as Physics courses: See item 5a of **Basic Requirements**.
 - b. Related courses: See item 5b of **Basic Requirements** but also including the courses in History of Science.
 - c. Physical Sciences 2 or 3, Physics 1a, 1b, 11a, or 11b, or any Core course may not be counted for concentration.
 - d. *Pass/Fail*: Two half-courses may be taken Pass/Fail. These may not include Physics 15a, 15b, 15c, 16, or 123.
 - e. The appropriate Advanced Placement credit or Harvard Chemistry placement credit may substitute for the required Chemistry course in item 1d, but the minimum of 13 half-courses total of actual courses taken in items 1a–f must be completed.
 - f. Additional information regarding UTEP, its courses and related activities, financial aid, the option of doing student teaching after graduation, and answers to other inquiries can be found in the UTEP Handbook (available in the UTEP Office, 222 Longfellow Hall). The UTEP administrator (617-495-3732) is responsible for advising all students who are considering or are enrolled in the program. In addition, each student in this option will have a Physics Department adviser for the subject area requirements.

Physics with Teacher Certification in both Physics and Chemistry

The requirements are the same as for *Teacher Certification in Physics*, except that:

1. Physics 143a and 181 are replaced by Chemistry 160 and 161.
2. An additional half-course, Chemistry 17 or 20, is also required; but the minimum number of subject area courses to be taken will still be 13.
3. If the UTEP program is not completed, Physics 143a must be taken to meet the basic requirements in Physics.

Physics with Teacher Certification in Physics and General Sciences

The requirements are the same as for *Teacher Certification in Physics*, with the addition of:

1. Two half-courses in Biology, normally Life Sciences 1a and 1b; but the minimum number of subject area courses to be taken will still be 13.

Physics with Teacher Certification in Physics and Mathematics

The requirements are the same as for *Teacher Certification in Physics*, except that:

1. The one half-course in a related subject (see item 5b of **Basic Requirements**) must be chosen from Mathematics, Statistics, or Computer Science courses (excluding Mathematics Xa, Xb).
2. One additional half-course in Probability and Statistics is required, normally Statistics 100 or HGSE H-102.
3. One additional half-course in Computer Science is required, normally chosen from Computer Science 50 or 51.

Note: It may be possible in items 2 or 3 to substitute other courses with a strong statistical or computer component, but in all cases the minimum number of subject-area courses taken must be 13.

ADVISING

Students interested in concentrating in Physics should discuss their Plans of Study with the Director or Assistant Director of Undergraduate Studies. When these are approved, each undergraduate who elects to concentrate in Physics is assigned an additional faculty adviser. If students do not request a change in adviser, they have the same adviser until they graduate. It is expected that students will discuss their programs and review their progress with faculty advisers at the beginning of each term. Students are told to seek advice at any time and can see their advisers at regularly scheduled office hours or by making an appointment. Students may also seek advice from the Director or Assistant Director of Undergraduate Studies at any time.

For up-to-date information on advising in Physics, please see the Advising Programs Office website: www.fas.harvard.edu/~advising/concentrations/Physics.html.

RESOURCES

The Science Center houses many modern facilities for undergraduate instruction in Physics. For example, concentrators will find most of the books and journals needed for their undergraduate courses in the Godfrey Lowell Cabot Science Library which is located there. (More advanced references are available in the Physics Research Library in the Jefferson Laboratory.) In addition, the computers used in undergraduate Physics courses are located in the Science Center as are the instructional laboratories, one in practical laboratory electronics and an advanced physics laboratory.

Students desiring to extend their research experience beyond the experiments available through the teaching laboratories may obtain access through the Physics 90r program to facilities for ongoing research in atomic and molecular physics in the Lyman Laboratory, solid-state physics in the Gordon McKay Laboratory, high energy physics in the High Energy Physics Laboratory, astrophysics through the Center for Astrophysics, and in biophysics through the various Biological Laboratories.

HOW TO FIND OUT MORE

For further information about the Physics concentration, the Physics Department, and related departments with a major physics component, the best single reference is the pamphlet *The SPS Guide to Physics and Related Fields*. Copies are available from the Assistant Director of Undergraduate Studies in Lyman 233. Information is also available at www.physics.harvard.edu/academics/undergrad.

Advice and personal consultation concerning the concentration can be obtained from the Director of Undergraduate Studies, Professor Howard Georgi, Jefferson 456, georgi@physics.harvard.edu (617-496-8293); or Assistant Director of Undergraduate Studies, Dr. David Morin, Lyman 233, morin@physics.harvard.edu (617-495-3257). For office hours, check the website: schwinger.harvard.edu/~georgi/schedule.htm.

ENROLLMENT STATISTICS

Number of Concentrators as of November

Concentrators	2002	2003	2004	2005	2006
Physics	90	88	78	74	75
Physics + another field	34	37	44	43	26
Another field + Physics	6	12	11	15	17