

# PHYSICS

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The overarching goal of the physics program is to train students—majors and nonmajors alike—to think like physicists, the hallmarks of which include: striving for fundamental explanations that have broad predictive power; appreciating that quantitative analysis is necessary for proper understanding; simplifying physical situations to their essentials to enable the development of mathematical models to explain and predict experimental data; and comparing experimental data from the natural world to theory.

To achieve this goal, we offer courses for physics majors who intend to further their study of physics or any STEM field in graduate school, as well as those physics majors who intend to go into law, consulting, financial services, technology industries, teaching, or any number of fields. Many students enroll in our introductory courses as a compulsory requirement of their STEM major; to satisfy a requirement for admission into medical school; or because they appreciate the quantitative training and intrinsic value offered by a basic understanding of modern physics. The director of undergraduate studies (DUS) can help students prepare for graduate school in physics by recommending appropriate electives to supplement the core courses. Research experience (PHYS 2710, 2720, 4710, and 4720) is an important aspect of preparing for graduate school.

The department offers two majors in Physics: the B.S. and the B.S. intensive major. Students in either program acquire advanced training in physics, mathematics, and related topics through the core courses. They use electives to design individualized programs with more depth or breadth, depending on their interests. Both degree programs require some research experience. PHYS 2710 and PHYS 2720, introductory research courses, are open to all students. Juniors and seniors, as part of the senior requirement, are required to enroll in PHYS 4710 and 4720—one term for the B.S. degree and two terms for the B.S. degree, intensive major. Combined majors are available in Mathematics and Physics, Astrophysics, Physics and Philosophy, and Physics and Geosciences.

## COURSES FOR NONMAJORS AND MAJORS

A guide to selecting physics courses is available to aid in course selection. Questions about placement should be addressed to the DUS.

**Introductory courses with no calculus requirement** Physics courses numbered 1200 or below are for students with little or no previous experience in physics who do not plan to major in the natural sciences. Many of these courses fulfill the science and/or quantitative reasoning distributional requirements. These courses have no college-level mathematics requirement and do not satisfy the medical school requirement.

## Introductory calculus-based lecture sequences

1. PHYS 1700, 1710 is aimed at students who are interested in the biological sciences or medicine. Knowledge of differential and integral calculus at the

level of MATH 1120 or equivalent is a prerequisite. MATH 1150 or (preferably) MATH 1160 should be taken concurrently with PHYS 1710. PHYS 1700 is a prerequisite for PHYS 1710.

2. PHYS 1800, 1810 is aimed at students who plan to major in the physical sciences or engineering. Calculus at the level of MATH 1120 is a prerequisite; MATH 1150 and MATH 1200 should be taken concurrently. PHYS 1800 or PHYS 2000 is a prerequisite for PHYS 1810.
3. PHYS 2000, 2010 is aimed at students with a strong background in mathematics and physics who plan to major in the physical sciences. Calculus at the level of MATH 1150 is presumed; MATH 1200 and either MATH 2220, MATH 2250, or MATH 2260, which are generally taken concurrently.
4. PHYS 2600, 2610 is intended for students who have had excellent prior training in mathematics and a solid foundation in physics. One of MATH 1200, ENAS 1510, PHYS 4000, or the equivalent should be taken concurrently with PHYS 2600, 2610. Students considering an alternative MATH course should check with the DUS in Physics.

**Introductory laboratories** Two different introductory laboratory sequences are offered: PHYS 1650L, 1660L, and PHYS 2050L, 2060L. Each of these laboratory courses earns one-half course credit. Students normally take the laboratory courses associated with the introductory physics sequence in which they are enrolled.

1. PHYS 1650L, 1660L is an introductory laboratory sequence aimed at students interested in engineering, the life sciences, and medicine. Related lecture courses are PHYS 1700, 1710, and PHYS 1800, 1810.
2. PHYS 2050L, 2060L is for students who plan to major in the physical sciences or engineering. Related lecture courses are PHYS 1800, 1810; PHYS 2000, 2010; and PHYS 2600, 2610. Students who take the lecture courses in their first year are advised to start this laboratory sequence with PHYS 2050L in the spring of their first year or in the fall of sophomore year.

**Advanced electives** A series of 3400-level electives explores special topics of interest to both majors and nonmajors. The electives are open to any student in Yale College who has completed a year of introductory calculus-based physics (PHYS 1700, 1710; or PHYS 1800, 1810; or PHYS 2000, 2010; or PHYS 2600, 2610). Physics courses numbered 3000 or higher count as electives for the major.

#### PREREQUISITES

**B.S. degree program** The prerequisites include an introductory lecture course sequence with a mathematics sequence equivalent to, or more advanced than, the corequisite of the physics sequence. The following options are appropriate: PHYS 1700, 1710 with MATH 1120, MATH 1150; or PHYS 1800, 1810 with MATH 1150, MATH 1200; or PHYS 2000, 2010 with MATH 1200 and either MATH 2220 or MATH 2250 or MATH 2260; or PHYS 2600, 2610 with MATH 1200, ENAS 1510, PHYS 4000, or equivalent. In addition, the laboratory course PHYS 2050L or the sequence PHYS 1650L, 1660L is required. Students who take these physics and mathematics courses starting in their first year may satisfy the prerequisites by the middle of their sophomore year. Students who begin taking physics courses in their sophomore year may also complete either the

standard or the intensive major. Students are advised to take mathematics courses throughout their first year at the appropriate level.

**B.S. degree program, intensive major** The prerequisites for the B.S. degree with an intensive major are the same as for the standard program.

#### REQUIREMENTS OF THE MAJOR

**Students are held to the requirements that were in place when they declared their major.** However, with approval from the DUS, the following requirements, updated for the academic year 2025-2026, may be fulfilled by students who declared the major in a prior term.

**B.S. degree program** Eight and one-half course credits are required beyond the prerequisites, including the senior project. Students must take a mathematics course at the level of, or more advanced than, PHYS 4000. Three courses at the core of the major, PHYS 4010, 4020, and either PHYS 4390 or 4400, involve advanced study of fundamental topics common to all branches of physics. PHYS 4010 and 4020 pertain to advanced classical physics (mechanics, statistical physics and thermodynamics, and electromagnetism), while the third, PHYS 4390 or 4400 covers quantum mechanics. PHYS 4010 must be taken before PHYS 4020, 4390, or 4400.

Because experiment is at the heart of the discipline, the major requires at least one laboratory course (PHYS 2060L or equivalent) and at least one term of independent research (PHYS 4710, 4720 or equivalent). Three advanced elective courses are also required. Suitable advanced courses are numbered 3000 or higher, such as the advanced laboratory PHYS 4450L, and 4000-level courses in Physics. Students may also find suitable advanced courses in other departments in the sciences, engineering, and mathematics. Courses taken to satisfy these requirements must be approved by the DUS. In order to pursue their individual interests in sufficient depth, many students choose to take more than the required number of advanced courses.

**B.S. degree program, intensive major** Ten and one-half course credits are required beyond the prerequisites, including the senior project. Students must take a mathematics course at the level of, or more advanced than, PHYS 4000. Five courses at the core of the major involve advanced study of fundamental topics common to all branches of physics. Three of the courses pertain to advanced classical physics: mechanics (PHYS 4100), statistical physics and thermodynamics (PHYS 4500), and electromagnetism (PHYS 4300). Two other courses incorporate quantum mechanics (PHYS 4390 or 4400 and PHYS 4410). Because the ideas build progressively: PHYS 4100 must precede PHYS 4390 or 4400; PHYS 4300 and PHYS 4390 or 4400 must precede PHYS 4410, and PHYS 4390 or 4400 must also precede or (with instructor permission) be taken concurrently with PHYS 4500.

Because experiment is at the heart of the discipline, the intensive major requires two laboratory courses (PHYS 2060L and PHYS 4450L or equivalent) and at least two terms of independent research (PHYS 4710, 4720 or equivalent). One advanced elective course is required to complete the program. Suitable advanced courses are numbered 3000 or higher, and include 4000-level courses in Physics. Students may also find suitable advanced courses in other departments in the sciences, engineering, and mathematics. Courses taken to satisfy these requirements must be approved by the

DUS. In order to pursue their individual interests in sufficient depth, many students choose to take more than the required number of advanced courses.

**Credit/D/Fail** No course taken Credit/D/Fail may be applied toward the requirements of either major, including prerequisites.

**Outside credit** Courses taken at another institution or during an approved summer or term-time study abroad program may count toward the major requirements with DUS approval.

#### SENIOR REQUIREMENT

**B.S. degree program** The senior requirement for the standard B.S. degree is fulfilled by receiving a passing grade on a one-term research project in PHYS 4710 or 4720 or equivalent. One enrollment of PHYS 4710 or 4720 taken at any time during junior or senior year counts as the senior requirement for the Physics major. Students should consult the DUS for further information.

**B.S. degree program, intensive major** The senior requirement for the intensive major is fulfilled by receiving a passing grade on a two-term research project (or two one-term research projects) in PHYS 4710 or 4720. Two enrollments of PHYS 4710 or 4720 taken at any time during junior or senior year counts as the senior requirement for the intensive Physics major. Students may take either PHYS 4710 or 4720 two times or they can take each course one time. Students should consult the DUS for further information.

#### ADVISING

All Physics majors in the sophomore, junior, and senior classes must have their programs approved by the DUS. First-year students and undeclared sophomores who are interested in Physics or related majors are encouraged to meet with the DUS to discuss their questions and proposed programs.

For both the standard B.S. degree and the B.S. degree with an intensive major, students are advised to begin the program in their first year to allow the greatest amount of flexibility in course selection. It is possible, however, to complete either program in a total of six terms, as illustrated below.

A program for a student completing the Physics B.S. in three years might be:

<b>First-Year or Sophomore</b>	<b>Sophomore or Junior</b>	<b>Senior</b>
PHYS 1700, 1710, or PHYS 1800, 1810, or PHYS 2000, 2010, or PHYS 2600, 2610	PHYS 2060L	PHYS 4390 or PHYS 4400
PHYS 2050L	PHYS 4000	PHYS 4710 or 4720
Mathematics corequisites	PHYS 4010	Two advanced electives
	PHYS 4020	
	One advanced elective	

A program for a student completing the intensive major in three years might be:

First-Year or Sophomore	Sophomore or Junior	Senior
PHYS 1700, 1710, or PHYS 1800, 1810, or PHYS 2000, 2010, or PHYS 2600, 2610	PHYS 2060L	PHYS 4450L
PHYS 2050L	PHYS 4000	PHYS 4400
Mathematics corequisites	PHYS 4100	PHYS 4500
	PHYS 4300	PHYS 4410
	One advanced elective	PHYS 4710
		PHYS 4720

## SUMMARY OF MAJOR REQUIREMENTS

### B.S. DEGREE

**Prerequisites** PHYS 1700, 1710 or PHYS 1800, 1810 or PHYS 2000, 2010 or PHYS 2600, 2610, with appropriate math coreqs, as indicated; PHYS 2050L or PHYS 1650L, 1660L

**Number of courses** 9 term courses for 8.5 course credits beyond prereqs (incl senior req)

**Specific courses required** PHYS 4010, 4020, and either PHYS 4390 or 4400, as indicated; PHYS 2060L or equivalent

**Distribution of courses** PHYS 4000 or other advanced math course; 3 advanced electives approved by DUS

**Senior requirement** One term of PHYS 4710 or 4720 or equivalent

### B.S. DEGREE, INTENSIVE MAJOR

**Prerequisites** PHYS 1700, 1710 or PHYS 1800, 1810 or PHYS 2000, 2010 or PHYS 2600, 2610, with appropriate math coreqs, as indicated; PHYS 2050L or PHYS 1650L, 1660L

**Number of courses** 11 term courses for 10.5 course credits beyond prereqs (incl senior req)

**Specific courses required** PHYS 4100, 4300, PHYS 4390 or 4400, 4410, 4500, as indicated; PHYS 2060L and PHYS 4450L or equivalent

**Distribution of courses** PHYS 4000 or other advanced math course; 1 advanced elective approved by DUS

**Senior requirement** Two terms of PHYS 4710 or 4720 or equivalent

### FACULTY OF THE DEPARTMENT OF PHYSICS

**Professors** †Charles Ahn, Yoram Alhassid, Thomas Appelquist, †Charles Bailyn, O. Keith Baker, Charles Baltay (*Emeritus*), Sean Barrett, †Joerg Bewersdorf, Helen Caines, †Hui Cao, Richard Casten (*Emeritus*), †Damon Clark, †Paolo Coppi, Sarah Demers, †Thierry Emonet, †Marla Geha, Steven Girvin, Larry Gladney, Leonid Glazman, Walter Goldberger, Jack Harris, John Harris (*Emeritus*), Karsten Heeger,

†Joe Howard, Francesco Iachello (*Emeritus*), †Sohrab Ismail-Beigi, Steve Lamoreaux, Konrad Lehnert, †Andre Levchenko, Reina Maruyama, Simon Mochrie, Vincent Moncrief, †John Murray, Daisuke Nagai, †Priyamvada Natarajan, †Andrew Neitzke, †Vidvuds Ozolins, Peter Parker (*Emeritus*), †Daniel Prober, Nicholas Read, †Robert Schoelkopf, †John Schotland, †Jurgen Schukraft, Ramamurti Shankar, Witold Skiba, †A. Douglas Stone, †Hong Tang, Paul Tipton, C. Megan Urry, †Frank van den Bosch, †Pieter van Dokkum, †John Wettlaufer, Michael Zeller (*Emeritus*)

**Associate Professors** †Michael Murrell, Nir Navon, Laura Newburgh, †Corey O'Hern, Nikhil Padmanabhan, David Poland, †Peter Rakich, Alison Sweeney

**Assistant Professors** Charles Brown, Meng Cheng, Laura Havener, †Yu He, Eduardo Higino da Silva Neto, Christopher Lynn, Benjamin Machta, †Owen Miller, Chiara Mingarelli, David Moore, Ian Moulton, †Shruti Puri, †Diana Qiu, †John Sous, †Logan Wright

**Senior Lecturer** Adriane Steinacker

**Lecturers** †Eun-Joo Ahn, Mehdi Ghiassi-Nejad, Caitlin Hansen, Stephen Irons, Stephen Konezny, Rona Ramos, †Barbara Cruvinel Santiago

†A joint appointment with primary affiliation in another department.