

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 469, 470, 471, and 472) 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 469 and PHYS 470, introductory research courses, are open to all students. Juniors and seniors, as part of the senior requirement, are required to enroll in PHYS 471 and 472—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 120 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 170, 171 is aimed at students who are interested in the biological sciences or medicine. Knowledge of differential and integral calculus at the level of MATH 112 or equivalent is a prerequisite. MATH 115 or (preferably) MATH 116 should be taken concurrently with PHYS 171. PHYS 170 is a prerequisite for PHYS 171.
2. PHYS 180, 181 is aimed at students who plan to major in the physical sciences or engineering. Calculus at the level of MATH 112 is a prerequisite; MATH 115 and 120 should be taken concurrently. PHYS 180 or PHYS 200 is a prerequisite for PHYS 181.
3. PHYS 200, 201 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 115 is presumed; MATH 120 and either MATH 222, 225, or 226, which are generally taken concurrently.
4. PHYS 260, 261 is intended for students who have had excellent prior training in mathematics and a solid foundation in physics. One of MATH 120, ENAS 151, PHYS 301, or the equivalent should be taken concurrently with PHYS 260, 261. Students considering an alternative MATH course should check with the DUS in Physics.

Introductory laboratories Two different introductory laboratory sequences are offered: PHYS 165L, 166L, and PHYS 205L, 206L. 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 165L, 166L is an introductory laboratory sequence aimed at students interested in engineering, the life sciences, and medicine. Related lecture courses are PHYS 170, 171, and PHYS 180, 181.
2. PHYS 205L, 206L is for students who plan to major in the physical sciences or engineering. Related lecture courses are PHYS 180, 181; PHYS 200, 201; and PHYS 260, 261. Students who take the lecture courses in their first year are advised to start this laboratory sequence with PHYS 205L in the spring of their first year or in the fall of sophomore year.

Advanced electives A series of 340-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 170, 171; or 180, 181; or 200, 201; or 260, 261). Physics courses more advanced than PHYS 290 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 170, 171 with MATH 112, 115; or PHYS 180, 181 with MATH 115, 120; or PHYS 200, 201 with MATH 120 and either 222 or 225 or 226; or PHYS 260, 261 with MATH 120, ENAS 151, PHYS 301, or equivalent. In addition, the laboratory sequence PHYS 205L, 206L or PHYS 165L, 166L 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

B.S. degree program Eight courses are required beyond the prerequisites, including the senior project. Students must take a mathematics course at the level of, or more advanced than, PHYS 301. Three courses at the core of the major, PHYS 401, 402, and either PHYS 439 or 440, involve advanced study of fundamental topics common to all branches of physics. PHYS 401 and 402 pertain to advanced classical physics (mechanics, statistical physics and thermodynamics, and electromagnetism), while the third, PHYS 439 or 440 covers quantum mechanics. PHYS 401 must be taken before PHYS 402, 439, or 440.

Three advanced elective courses are also required. Suitable advanced courses are numbered higher than PHYS 290, such as the advanced laboratory PHYS 382L, and 400-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 courses are required beyond the prerequisites, including the senior project. Students must take a mathematics course at the level of, or more advanced than, PHYS 301. 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 410), statistical physics and thermodynamics (PHYS 420), and electromagnetism (PHYS 430). Two other courses incorporate quantum mechanics (PHYS 440 and 441). Because the ideas build progressively: PHYS 410 must precede PHYS 440; PHYS 430 and 440 must precede PHYS 441, and PHYS 440 must also precede PHYS 420.

Because experiment is at the heart of the discipline, the intensive major requires one term of advanced laboratory (PHYS 382L or equivalent) and at least two terms of independent research (PHYS 471, 472 or equivalent). One advanced elective course is required to complete the program. Suitable advanced courses are more advanced than PHYS 290 and include 400-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 ten advanced courses.

Credit/D/Fail courses Courses taken Credit/D/Fail may not be counted toward the requirements of either major, including prerequisites.

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 471 or 472 or

equivalent. One enrollment of PHYS 471 or 472 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 in PHYS 471 or 472. Two enrollments of PHYS 471 or 472 taken at any time during junior or senior year counts as the senior requirement for the intensive Physics major. Students may take either PHYS 471 or 472 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:

First-Year or Sophomore	Sophomore or Junior	Senior
PHYS 170, 171, or 180, 181, or 200, 201, or 260, 261	PHYS 206L	PHYS 439 or PHYS 440
PHYS 205L	PHYS 301	PHYS 471 or 472
Mathematics corequisites	PHYS 401	Two advanced electives
	PHYS 402	
	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 170, 171, or 180, 181, or 200, 201, or 260, 261	PHYS 206L	PHYS 382L
PHYS 205L	PHYS 301	PHYS 420
Mathematics corequisites	PHYS 410	PHYS 441
	PHYS 430	PHYS 471
	PHYS 440	PHYS 472
		One advanced elective

SUMMARY OF MAJOR REQUIREMENTS

B.S. DEGREE

Prerequisites PHYS 170, 171 or 180, 181 or 200, 201 or 260, 261, with appropriate math coreqs, as indicated; PHYS 205L, 206L or PHYS 165L, 166L

Number of courses 8 term courses beyond prereqs (incl senior req)

Specific courses required PHYS 401, 402, and either PHYS 439 or 440, as indicated

Distribution of courses PHYS 301 or other advanced math course; 3 advanced electives approved by DUS

Senior requirement PHYS 471 or 472 or equivalent

B.S. DEGREE, INTENSIVE MAJOR

Prerequisites PHYS 170, 171 or 180, 181 or 200, 201 or 260, 261, with appropriate math coreqs, as indicated; PHYS 205L, 206L or PHYS 165L, 166L

Number of courses 10 term courses beyond prereqs (incl senior req)

Specific courses required PHYS 410, 440, 441, 420, 430, as indicated; PHYS 382L or equivalent

Distribution of courses PHYS 301 or other advanced math course; 1 advanced elective approved by DUS

Senior requirement Two terms of PHYS 471 or 472

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COURSES WITH NO CALCULUS REQUIREMENT

These courses are designed for non-science students with little or no background in physics. None has a college-level mathematics requirement. Each course may count toward the distributional requirements in Science and/or Quantitative Reasoning. These courses are normally numbered below 100.

CALCULUS-BASED INTRODUCTORY PHYSICS LECTURE COURSES

The four introductory physics course sequences listed below are calculus-based. Students should have the appropriate background in mathematics to take these courses.

Completion of an introductory sequence also prepares students for a series of 340-level electives, which cover special topics of interest to both majors and nonmajors.

For more details, please see the Guide to Selecting the Best Physics Courses for You.

- PHYS 170 and PHYS 171 are for students who are interested in the medical and biological sciences. Knowledge of differential and integral calculus at the level of MATH 112, or equivalent is a prerequisite for PHYS 170 and PHYS 171. PHYS 170 is a prerequisite for PHYS 171. MATH 115 should be taken concurrently with PHYS 171.
- PHYS 180 and PHYS 181 are for students with some previous background in physics and mathematics who plan to major in the physical sciences. Calculus at the level of MATH 112 is a prerequisite; PHYS 180 or PHYS 200 is a prerequisite for PHYS 181. MATH 115 and MATH 120 should be taken concurrently.
- PHYS 200 and PHYS 201 are for students with a strong background in mathematics and physics who plan to major in the physical sciences. Calculus at the level of MATH 115 is presumed; MATH 120 and either MATH 225, 226, or 222, are generally taken concurrently.
- PHYS 260 and PHYS 261 are for students who have excellent training in physics and mathematics and a flair for mathematical methods and quantitative analysis. One of the following: MATH 120, ENAS 151, PHYS 301, or the equivalent should be taken concurrently.

LABORATORY COURSES

- PHYS 165L and PHYS 166L do not require a strong high school physics laboratory preparation. Related lecture courses are PHYS 170, PHYS 171 or PHYS 180, PHYS 181.
- PHYS 205L and PHYS 206L are for students who plan to major in the physical sciences or engineering. The related lecture courses are PHYS 180, PHYS 181, or PHYS 200, PHYS 201, or PHYS 260, PHYS 261. Students are advised to start this laboratory sequence in the spring of the first year or the fall of the sophomore year.

The following table summarizes some important information about the lecture and laboratory courses described above.

	Meets Medical School Requirement	Acceptable for Physics Major	Math Taken Concurrently
PHYS 050– PHYS 120	no	no	none
PHYS 170, PHYS 171	yes	yes	MATH 115
PHYS 180, PHYS 181	yes	yes	MATH 115, MATH 120
PHYS 200, PHYS 201	yes	yes	MATH 120, and MATH 222, MATH 225, or MATH 226

PHYS 260, PHYS 261	yes	yes	One of MATH 120, ENAS 151, PHYS 151, or PHYS 301, or equivalent in multivariable calculus
PHYS 165L, PHYS 166L	yes	yes	
PHYS 205L, PHYS 206L	yes	yes	

Further information about undergraduate physics at Yale can be found on the department website.

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*), †Paolo Coppi, Sarah Demers, †Michel Devoret, †Thierry Emonet, †Marla Geha, Steven Girvin, Larry Gladney, Leonid Glazman, Walter Goldberger, Jack Harris, John Harris (*Emeritus*), Karsten Heeger (*Chair*), †Victor Henrich (*Emeritus*), †Joe Howard, Francesco Iachello (*Emeritus*), †Sohrab Ismail-Beigi, Steve Lamoreaux, †Andre Levchenko, Reina Maruyama, Simon Mochrie, Vincent Moncrief, Daisuke Nagai, †Priyamvada Natarajan, †Andrew Neitzke, †Corey O'Hern, Peter Parker (*Emeritus*), †Daniel Prober, Nicholas Read, †Peter Schiffer, †Robert Schoelkopf, †John Schotland, 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 †Damon Clark, †Michael Murrell, Nikhil Padmanabhan, David Poland, †Peter Rakich, Alison Sweeney

Assistant Professors Charles Brown, Meng Cheng, †Yu He, Eduardo Higino da Silva Neto, Benjamin Machta, Owen Miller, David Moore, Ian Moulton, †John Murray, Nir Navon, Laura Newburgh, Shruti Puri, †Diana Qiu

Senior Lecturers Sidney Cahn, Adriane Steinacker

Lecturers Mehdi Ghiassi-Nejad, Adrian Gozar, Caitlin Hansen, Stephen Irons, Rona Ramos

†A joint appointment with primary affiliation in another department.

See visual roadmap of the requirements.

View Courses