APPLIED PHYSICS

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Physics is the study of the fundamental laws of nature. Applied physics uses these laws to understand phenomena that have practical applications. Engineering in turn makes use of these phenomena for human purposes. Applied physics thus forms a link between the fundamental laws of nature and their applications. Students majoring in Applied Physics take courses in both physics and engineering, as well as courses specifically in applied physics. Students completing the program in Applied Physics are prepared for graduate study in applied physics, in physics, in nanoscience, or in engineering, and, with appropriate prerequisites, in medicine; or they may choose careers in a wide range of technical and commercial fields, or in fields such as technical writing or patent law that draw on interdisciplinary subjects.

Contemporary physical science and engineering are becoming increasingly interdisciplinary. Traditional boundaries between fields have blurred, and new areas are constantly emerging, e.g., nanotechnology. The Applied Physics major provides a flexible framework on which students can build a curriculum tailored to their own interests, in consultation with the director of undergraduate studies (DUS).

PREREQUISITES

During their first year, students interested in Applied Physics should start by taking courses in mathematics, and in physics if possible, appropriate to their level of preparation. The choice between different starting points is generally made based on performance on Advanced Placement tests. The multiplicity of choices facing students interested in this general area indicates the importance of informed advice for first-year students. Students should consult freely with DUSs and individual faculty members in their departments of interest to optimize choices and to ensure maximum flexibility at the time a major is selected.

The required prerequisites for students interested in Applied Physics include two physics courses and one physics lab; APHY 151 or MATH 120; and PHYS 301 (or APHY 194 with either MATH 222 or MATH 225 or MATH 226).

The recommended starting courses in physics are PHYS 200 and 201. These courses should be taken in the first year by students who have a strong preparation in mathematics and physics. Students with a particularly strong background in physics and mathematics may take PHYS 260 and 261 instead. Students who are less well prepared in physics and mathematics may choose to take PHYS 180 and 181 during their first year, or PHYS 200 and 201 during their sophomore year after they have taken additional mathematics courses. One laboratory course, PHYS 166L or 206L, should be taken at some time during the first or second year.

REQUIREMENTS OF THE MAJOR

The major in Applied Physics requires eight courses beyond the introductory sequence. Two of these must be APHY 471 and 472. All majors are also required to take APHY 322, APHY 439 or PHYS 440, and APHY 420, or equivalents. The three remaining advanced

courses should comprise an area of focus. For example, a student interested in solid-state and/or quantum electronics might choose from APHY 321, 448, 449, EENG 320, and 325. A student interested in the physics of materials and/or nanoscience might choose from APHY 448, 449, CHEM 220, and MENG 285. Many other focus areas are possible.

Credit/D/Fail All courses required for the major, beyond the prerequisites, must be taken for a letter grade, with the single exception that one such course may be taken Credit/D/Fail with permission of the DUS. The senior special projects, APHY 471 and 472, may only be taken for a letter grade.

SENIOR REQUIREMENT

Seniors must complete an independent research project, taken as APHY 471 and 472. The independent research project is under the supervision of a faculty member in Applied Physics, Physics, Engineering, or related departments. The project may be started in the junior year and continued into the senior year. Students planning to do a research project should contact the DUS as early as possible to discuss available options and general requirements.

ADVISING

The Applied Physics major provides various programs corresponding to a range of student interests. Substitutions of equivalent courses may be permitted. Students interested in an Applied Physics major should contact the DUS as early as possible, and in any case by the end of their sophomore year.

A well-prepared student interested in materials physics or quantum electronics who starts the senior research in the junior year might elect the following course sequence:

First-Year	Sophomore	Junior	Senior
APHY 151	APHY 322	APHY 472	APHY 448
PHYS 200	APHY 439	EENG 320	APHY 449
PHYS 201	PHYS 301	APHY 420	APHY 471
PHYS 206L			

A student interested in alternative energy who starts physics in the sophomore year and conducts research in the senior year might elect:

First-Year	Sophomore	Junior	Senior
MATH 120	PHYS 200	APHY 322	APHY 448
	PHYS 201	APHY 439	APHY 471
	PHYS 206L	EENG 320	APHY 472
	PHYS 301	APHY 420	EENG 406

REQUIREMENTS OF THE MAJOR

Prerequisites PHYS 180, 181, or 200, 201, with appropriate math coreqs and PHYS 166L or 206L; APHY 151 or MATH 120; PHYS 301 (or APHY 194 with either MATH 222 or MATH 225 or MATH 226)

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

Distribution of courses 3 adv courses in physical or mathematical sciences or engineering in area of focus, with DUS approval

Specific courses required APHY 322, APHY 439 or PHYS 440, and APHY 420, or equivalents

Substitution permitted Any relevant course approved by DUS

Senior requirement APHY 471 and 472

Prerequisites

- 2 physics courses and 1 physics lab
- APHY 151 (or MATH 120) and PHYS 301 (or APHY 194 with MATH 222 or MATH 225 or MATH 226)

Requirements: 8 courses (8 credits) beyond the prerequisites

- APHY 322
- APHY 439 or PHYS 440
- APHY 420
- 3 advanced courses within area of focus
- APHY 471
- APHY 472

Contemporary science and engineering are becoming increasingly interdisciplinary. Traditional boundaries between fields have blurred, and new areas such as nanotechnology and artificially structured materials are constantly emerging. Applied physics combines study of the laws of nature at a fundamental level with a focus on technological applications to provide solutions for important societal problems. As a result, it provides an essential link between physics and engineering. The range of phenomena, materials, devices, and systems benefiting from research in applied physics is unmatched in scope and importance.

The Applied Physics major offers a unique combination of depth and flexibility, allowing students to maximize their professional development while pursuing their particular interests. Majors take courses in physics, engineering, and applied physics and are prepared for graduate study in physics, applied physics, engineering, nanoscience and, with appropriate prerequisites, medicine or law.

Prospective majors should start by taking courses in mathematics and physics appropriate to their level of preparation. Because computers are so fundamental to the practical applications of physics, students are also strongly encouraged to take a course on the use of computers early in their career. In addition to the prerequisites, all majors take three upper-level core courses in topics that are foundational for modern science and engineering:

- APHY 322, Electromagnetic Waves and Devices
- APHY 439, Basic Quantum Mechanics or PHYS 440, Quantum Mechanics and Natural Phenomena I
- APHY 420, Thermodynamics and Statistical Mechanics

The remaining requirements of the major allow students to focus their coursework and research on an individual area of scientific interest, provided it contains a significant physics component. Majors choose three electives in consultation with the director of undergraduate studies (DUS) and conduct two terms of independent research supervised by a faculty adviser from Applied Physics, Physics, one of the engineering departments, the Medical School, or related departments. The electives should relate to the research topic so that courses and research are intellectually coherent.

For more information, please contact the DUS, Daniel Prober (daniel.prober@yale.edu), who welcomes consultation with students regarding their programs at any time. Additional details about the program are available on the department website. For an overview of Applied Physics at Yale, watch the department's YouTube video.

FACULTY OF THE DEPARTMENT OF APPLIED PHYSICS

Professors Charles Ahn, †Sean Barrett, Hui Cao, Michel Devoret, Paul Fleury (*Emeritus*), †Steven Girvin, †Leonid Glazman, †Jack Harris, Victor Henrich (*Emeritus*), Sohrab Ismail-Beigi, Simon Mochrie, †Corey O'Hern, Vidvuds Ozolins, Daniel Prober, Nicholas Read, Peter Schiffer, Robert Schoelkopf, †Ramamurti Shankar, †Mitchell Smooke, A. Douglas Stone, †Hongxing Tang, Robert Wheeler (*Emeritus*), Werner Wolf (*Emeritus*)

Associate Professors †Michael Choma, Peter Rakich

Assistant Professors Yu He, Owen Miller, Shruti Puri

†A joint appointment with primary affiliation in another department.

View Courses

Courses

* **APHY 050a or b / ENAS 050a or b / PHYS 050a or b, Science of Modern Technology and Public Policy** Daniel Prober
Examination of the science behind selected advances in modern technology and implications for public policy, with focus on the scientific and contextual basis of each advance. Topics are developed by the participants with the instructor and with guest lecturers, and may include nanotechnology, quantum computation and cryptography, renewable energy technologies, optical systems for communication and medical diagnostics, transistors, satellite imaging and global positioning systems, large-scale immunization, and DNA made to order. Enrollment limited to first-year students. SC

* **APHY 100b / ENAS 100b / EPS 105b / EVST 100b / PHYS 100b, Energy, Environment, and Public Policy** Daniel Prober
The technology and use of energy. Impacts on the environment, climate, security, and economy. Application of scientific reasoning and quantitative analysis. Intended for non–science majors with strong backgrounds in math and science. QR, SC RP

[APHY 110, The Technological World]

APHY 151a or b / ENAS 151a or b / PHYS 151a or b, Multivariable Calculus for Engineers Staff
An introduction to multivariable calculus focusing on applications to engineering problems. Topics include vector-valued functions, vector analysis, partial differentiation, multiple integrals, vector calculus, and the theorems of Green, Stokes, and Gauss. Prerequisite: MATH 115 or equivalent. QR

APHY 194a or b / ENAS 194a or b, Ordinary and Partial Differential Equations with Applications Staff
Basic theory of ordinary and partial differential equations useful in applications. First- and second-order equations, separation of variables, power series solutions, Fourier series, Laplace transforms. Prerequisites: ENAS 151 or MATH 120 or equivalent, and knowledge of matrix-based operations. QR

APHY 293a / PHYS 293a, Einstein and the Birth of Modern Physics A Douglas Stone
The first twenty-five years of the 20th century represent a turning point in human civilization as for the first time mankind achieved a systematic and predictive understanding of the atomic level constituents of matter and energy, and the mathematical laws which describe the interaction of these constituents. In addition, the General Theory of Relativity opened up for the first time a quantitative study of cosmology, of the history of the universe as a whole. Albert Einstein was at the center of these breakthroughs, and also became an iconic figure beyond physics, representing scientist genius engaged in pure research into the fundamental laws of nature. This course addresses the nature of the transition to modern physics, underpinned by quantum and relativity theory, through study of Einstein's science, biography, and historical context. It also presents the basic concepts in electromagnetic theory, thermodynamics and statistical mechanics, special theory of relativity, and quantum mechanics which were central to this revolutionary epoch in science. Prerequisites: Two terms of PHYS 170, 171, or PHYS 180, 181, or PHYS 200, 201, or PHYS 260, 261, or one term of any of these course with permission of instructor. QR, SC

APHY 320a / EENG 320a, Semiconductor Devices Hong Tang
An introduction to the physics of semiconductors and semiconductor devices. Topics include crystal structure; energy bands in solids; charge carriers with their statistics and dynamics; junctions, p-n diodes, and LEDs; bipolar and field-effect transistors; and device fabrication. Additional lab one afternoon per week. Prepares for EENG 325 and 401. Recommended preparation: EENG 200. PHYS 180 and 181 or permission of instructor QR, SC

APHY 418b / EENG 402b, Advanced Electron Devices Mengxia Liu
The science and technology of semiconductor electron devices. Topics include compound semiconductor material properties and growth techniques; heterojunction, quantum well and superlattice devices; quantum transport; graphene and other 2D material systems. Formerly EENG 418. Prerequisite: EENG 320 or equivalent. QR, SC

* **APHY 420a / PHYS 420a, Thermodynamics and Statistical Mechanics** Eduardo Higino da Silva Neto
This course is subdivided into two topics. We study thermodynamics from a purely macroscopic point of view and then we devote time to the study of statistical mechanics,

the microscopic foundation of thermodynamics. Prerequisites: PHYS 301, 410, and 440 or permission of instructor. QR, SC

APHY 439a / PHYS 439a, Basic Quantum Mechanics Vidvuds Ozolins
The basic concepts and techniques of quantum mechanics essential for solid-state physics and quantum electronics. Topics include the Schrödinger treatment of the harmonic oscillator, atoms and molecules and tunneling, matrix methods, and perturbation theory. Prerequisites: PHYS 181 or 201, PHYS 301, or equivalents, or permission of instructor. QR, SC

APHY 448a / PHYS 448a, Solid State Physics I Yu He
The first term of a two-term sequence covering the principles underlying the electrical, thermal, magnetic, and optical properties of solids, including crystal structure, phonons, energy bands, semiconductors, Fermi surfaces, magnetic resonances, phase transitions, dielectrics, magnetic materials, and superconductors. Prerequisites: APHY 322, 439, PHYS 420. QR, SC

* **APHY 450a / ENAS 450a / MENG 450a, Advanced Synchrotron Techniques and Electron Spectroscopy of Materials** Charles Ahn
Introduction to concepts of advanced x-ray and electron-based techniques used for understanding the electronic, structural, and chemical behavior of materials. Students learn from world-leading experts on fundamentals and practical applications of various diffraction, spectroscopy, and microscopy methods. Course highlights the use of synchrotrons in practical experiments. Prerequisites: physics and quantum mechanics/physical chemistry courses for physical science and engineering majors, or by permission of instructor. QR, SC

APHY 458a / PHYS 458a, Principles of Optics with Applications Hui Cao
Introduction to the principles of optics and electromagnetic wave phenomena with applications to microscopy, optical fibers, laser spectroscopy, and nanostructure physics. Topics include propagation of light, reflection and refraction, guiding light, polarization, interference, diffraction, scattering, Fourier optics, and optical coherence. Prerequisite: PHYS 430. QR, SC

* **APHY 469a or b, Special Projects** Daniel Prober
Faculty-supervised individual or small-group projects with emphasis on research (laboratory or theory). Students are expected to consult the director of undergraduate studies and appropriate faculty members to discuss ideas and suggestions for suitable topics. This course may be taken more than once, is graded pass/fail, is limited to Applied Physics majors, and does not count toward the senior requirement. Permission of the faculty adviser and of the director of undergraduate studies is required.

* **APHY 471a and APHY 472b, Senior Special Projects** Daniel Prober
Faculty-supervised individual or small-group projects with emphasis on research (laboratory or theory). Students are expected to consult the director of undergraduate studies and appropriate faculty members to discuss ideas and suggestions for suitable topics. This course may be taken more than once and is limited to Applied Physics majors in their junior and senior years. Permission of the faculty adviser and of the director of undergraduate studies is required.