

# APPLIED PHYSICS

**Director of undergraduate studies:** Daniel Prober, 417 BCT, 432-4280, [daniel.prober@yale.edu](mailto:daniel.prober@yale.edu); [appliedphysics.yale.edu](http://appliedphysics.yale.edu)

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.

## PREREQUISITES

During their first year, students interested in Applied Physics should start by taking courses in mathematics, and physics if possible, appropriate to their level of preparation. The choice between different starting points is generally made on the basis of performance on Advanced Placement tests; see the First-year Student Website for more information.

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 directors of undergraduate studies 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 prerequisite requirements for the Class of 2021 and previous classes** Students who declared their major under previous requirements, must follow the prerequisite requirements, as indicated when they declared.

**The prerequisite requirements for the Class of 2022 and subsequent classes** 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.

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 more 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, 439, and APHY 420 or equivalents. The three remaining advanced courses should focus on a particular area of concentration. 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, 450, and MENG 285. Many other concentrations are possible.

## 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 director of undergraduate studies as early as possible to discuss available options and general requirements.

## ADVISING

The Applied Physics major provides for 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 director of undergraduate studies as early as possible, and in any case by the end of the 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 471 | APHY 448 |
| PHYS 200   | APHY 439  | EENG 320 | APHY 449 |
| PHYS 201   | PHYS 301  | APHY 420 | APHY 472 |
| 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)

**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 concentration, with DUS approval

**Specific courses required** APHY 322, 439, APHY 420, or equivalents

**Substitution permitted** Any relevant course approved by DUS

**Senior requirement** APHY 471 and 472

## FACULTY OF THE DEPARTMENT OF APPLIED PHYSICS

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

**Associate Professors** Liang Jiang, Peter Rakich

**Assistant Professors** †Michael Choma, Owen Miller

†A joint appointment with primary affiliation in another department.

## Courses

\* **APHY 050a / PHYS 050a, 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. Preregistration required; see under First-Year Seminar Program. SC RP

\* **APHY 100b / ENAS 100b / EVST 100b / G&G 105b / PHYS 100b, Energy Technology and Society** Daniel Prober, Michael Oristaglio, and Julie Paquette

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 110b / ENAS 110b, The Technological World** Owen Miller

An exploration of modern technologies that play a role in everyday life, including the underlying science, current applications, and future prospects. Examples include solar cells, light-emitting diodes (LEDs), computer displays, the global positioning system, fiber-optic communication systems, and the application of technological advances to medicine. For students not committed to a major in science or engineering; no college-level science or mathematics required. Prerequisite: high school physics or chemistry. QR, SC

**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 RP

**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 equivalent, and knowledge of matrix-based operations. QR RP

**APHY 321b / EENG 401b, Semiconductor Silicon Devices and Technology** Tso-Ping Ma

Introduction to integrated circuit technology, theory of semiconductor devices, and principles of device design and fabrication. Laboratory involves the fabrication and analysis of semiconductor devices, including Ohmic contacts, Schottky diodes, p-n junctions, solar cells, MOS capacitors, MOSFETs, and integrated circuits. Prerequisite: EENG 320 or equivalent or permission of instructor. QR, SC

**APHY 322b, Electromagnetic Waves and Devices** Michel Devoret

Introduction to electrostatics and magnetostatics, time varying fields, and Maxwell's equations. Applications include electromagnetic wave propagation in lossless, lossy, and metallic media and propagation through coaxial transmission lines and rectangular waveguides, as well as radiation from single and array antennas. Occasional experiments and demonstrations are offered after classes. Prerequisites: PHYS 180, 181, or 200, 201. QR, SC

**\* APHY 418b / EENG 418b, Heterojunction Devices** Mark Reed

The science and technology of semiconductor and semiconductor device physics, with emphasis on contemporary heterojunction devices. Compound semiconductor material properties and growth techniques; high speed and millimeter-wave devices; quantum well and superlattice devices; and device modeling. A laboratory component involves device fabrication and measurement. Prerequisite: APHY 439 or equivalent. QR, SC

**\* APHY 420a / PHYS 420a, Thermodynamics and Statistical Mechanics** Nir Navon

An introduction to the laws of thermodynamics and their theoretical explanation by statistical mechanics. Applications to gases, solids, phase equilibrium, chemical equilibrium, and boson and fermion systems. Prerequisites: PHYS 301, 410, and 440 or permission of instructor. QR, SC

**APHY 439a / PHYS 439a, Basic Quantum Mechanics** Liang Jiang

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** Sohrab Ismail-Beigi

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 449b / PHYS 449b, Solid State Physics II** Vidvuds Ozolins

The second term of the sequence described under APHY 448. QR, SC

**\* APHY 450b / ENAS 450b / MENG 450b, 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 470b, Statistical Methods with Applications in Science and Finance** Sohrab Ismail-Beigi

Introduction to key methods in statistical physics with examples drawn principally from the sciences (physics, chemistry, astronomy, statistics, biology) as well as added examples from finance. Students learn the fundamentals of Monte Carlo, stochastic random walks, and analysis of covariance analytically as well as via numerical exercises. Prerequisites: ENAS 194, MATH 222, and ENAS 130, or equivalents. QR, SC

**\* APHY 471a or b and APHY 472a 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. These courses may be taken at any appropriate time in the student's career; they may be taken more than once. Permission of the faculty adviser and of the director of undergraduate studies is required.