APPLIED PHYSICS

Becton Center, 203.432.2210
http://appliedphysics.yale.edu
M.S., M.Phil., Ph.D.

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Associate Professors Michael Choma (Biomedical Engineering), Peter Rakich

Assistant Professors Yu He, Owen Miller, Shruti Puri

FIELDS OF STUDY
Fields include areas of theoretical and experimental condensed-matter and materials physics, optical and laser physics, quantum science, quantum information, and nanoscale science. Specific programs include surface and interface science, first principles electronic structure methods, photonic materials and devices, complex oxides, magnetic and superconducting artificially engineered systems, quantum computing and superconducting device research, quantum transport, quantum optics, and random lasers.

INTEGRATED GRADUATE PROGRAM IN PHYSICAL AND ENGINEERING BIOLOGY (PEB)
Students applying to the Ph.D. program in Applied Physics may also apply to be part of the PEB program. See the description under Non-Degree-Granting Programs, Councils, and Research Institutes for course requirements, and http://peb.yale.edu for more information about the benefits of this program and application instructions.

SPECIAL REQUIREMENTS FOR THE PH.D. DEGREE
The requirements for a Ph.D. in applied physics include passing at least nine course units. Courses such as Dissertation Research, Master’s Thesis, or seminars do not count towards the nine-course requirement, but two terms of Special Investigation courses are acceptable. Other than the Special Investigation courses, the courses counting toward the nine-course requirement must be full-credit graduate courses. Courses outside of those identified as acceptable in the departmental degree guidelines must
have a clear technical, scientific, or mathematical focus that is related to applied physics in the judgement of the student’s adviser and the DGS.

Within the nine-course requirement, students must pass the three core courses, unless they are substituted or waived with approval by the DGS. The three core courses are Electromagnetic Theory I (PHYS 502), Quantum Mechanics I (PHYS 508), and Statistical Physics I (PHYS 512).

Students must also take the Research in Applied Physics Seminar (APHY 576) and the Responsible Conduct in Research for Physical Scientists Seminar (APHY 590).

Students typically complete most of their course requirements in the first year, and sufficient progress toward meeting the course requirements is necessary to remain in good standing in the program. Note that the required courses are just the minimum, and students are strongly encouraged to consult with their adviser about taking additional courses that are needed to facilitate their dissertation research.

By the end of the first year, students must find a research adviser who is willing to supervise a project that is consonant with the research program of that faculty. Research advisers must have an appointment in the Graduate School and be engaged in research that falls broadly within the subject of applied physics, although they do not need to be members of the department’s faculty.

After completing coursework, the next step toward a degree is admission to candidacy, indicating that the student is prepared to do original and independent research. To be admitted to candidacy, students must submit a written research prospectus and pass an area examination early in their third year. If a student has faced unusual circumstances, this deadline can be extended, with the support of the research adviser and approval of the DGS.

There is no foreign language requirement.

Teaching experience is regarded as an integral part of the graduate training program at Yale University, and all applied physics graduate students are required to serve as teaching fellows for two terms, typically during years two and three. Teaching duties normally involve assisting in laboratories or discussion sections and grading papers. Teaching duties are not expected to require more than ten hours per week. Students are not permitted to teach during the first year of study. Students who require additional support from the Graduate School must teach for up to an additional two terms, if needed.

If a student was admitted to the program having earned a score of less than 26 on the Speaking Section of the Internet-based TOEFL, the student will be required to take an English as a Second Language (ESL) course each term at Yale until the Graduate School’s Oral English Proficiency standard has been met. This must be achieved by the end of the third year in order for the student to remain in good standing.

HONORS REQUIREMENT

In order to remain in good standing in the program, students are expected make steady progress in meeting their course requirements and to obtain Honors grades in at least two full-term courses by the end of their fourth term of full-time study. Courses such as Master’s Thesis, seminars, or Special Investigations cannot be used to fulfill the
requirement for two Honors grades. An extension may be granted on a case-by-case basis at the discretion of the DGS, in consultation with the student’s adviser. Students are also expected to maintain an average grade of High Pass during their time at Yale, following the averaging methodology determined by the Graduate School.

MASTER’S DEGREES

M.Phil. See Degree Requirements under Policies and Regulations.

M.S. Students may apply for a terminal master’s degree in applied physics. For the M.S. degree, the requirements are that the student pass eight full-credit graduate courses (not seminars), typically courses similar to those that would meet the course requirements for the Ph.D. No more than two of the courses may be Special Investigations. Students may substitute other graduate courses with a clear technical, scientific, or mathematical focus that is related to applied physics in the judgement of the student’s adviser and the DGS. An average grade of at least High Pass is required, with at least one grade of Honors. This terminal degree program is normally completed in one year. Doctoral students who withdraw from the Ph.D. program may be eligible to receive the M.S. if they have met the above requirements and have not already received the M.Phil.

Program materials are available upon e-mail request to applied.physics@yale.edu, or at http://appliedphysics.yale.edu.

COURSES

APHY 506a, Basic Quantum Mechanics  Robert Schoelkopf
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.

APHY 526a, Explorations in Physics and Computation  Logan Wright
Computation has taken on an important, often central, role in both the practice and conception of physical science and engineering physics. This relationship is intricate and multifaceted, including computation for physics, computation with physics, and computation as a lens through which to understand physical processes. This course takes a more or less random walk within this space, surveying ideas and technologies that either apply computation to physics, that understand physical phenomena through the lens of computation, or that use physics to perform computation. Given the extent to which machine learning methods are currently revolutionizing this space of ideas, we focus somewhat more on topics related to modern machine learning, as opposed to other sorts of algorithms and computation. Since it is covered more deeply in other courses, we do not extensively cover error-corrected/fault tolerant quantum information processing, but we do frequently consider quantum physics. The course does not provide a systematic overview of any one topic, but rather a sampling of ideas and concepts relevant to modern research challenges. It is therefore intended for graduate students in early years of their program or research-inclined senior undergraduate students contemplating a research career. As a result, in addition to the scientific topics at hand, key learning goals include the basics of literature review, presentation, collegial criticism (peer review), and synthesizing new research ideas. Evaluation is primarily through two projects, one a lecture reviewing a topic area of
interest and one a tutorial notebook providing worked numerical examples/code meant to develop or introduce a concept. Prior experience with Python is ideal, but can be learned as part of the coursework. Students should ideally be familiar with quantum mechanics, including density matrices and some phase-space methods, but this applies to only small fraction of the course. The course is primarily a survey-level overview of many topics, not a deep dive into any one topic. As a result, students who have extensive background on many of the topics described in the syllabus are welcome to participate but should speak with the instructor beforehand so we can determine if their learning goals can be met.

APHY 548a / ENAS 850a / PHYS 548a, Solid State Physics I  Yu He
A two-term sequence (with APHY 549) covering the principles underlying the electrical, thermal, magnetic, and optical properties of solids, including crystal structures, phonons, energy bands, semiconductors, Fermi surfaces, magnetic resonance, phase transitions, and superconductivity.

APHY 549b / ENAS 851b / PHYS 549b, Solid State Physics II  Sohrab Ismail-Beigi
A two-term sequence (with APHY 548) covering the principles underlying the electrical, thermal, magnetic, and optical properties of solids, including crystal structures, phonons, energy bands, semiconductors, Fermi surfaces, magnetic resonance, phase transitions, and superconductivity.

APHY 576a, Topics in Applied Physics Research  Vidvuds Ozolins
The course introduces the fundamentals of applied physics research to graduate students in the Department of Applied Physics in order to introduce them to resources and opportunities for research activities. The content of the class includes overview presentations from faculty and other senior members of the department and related departments about their research and their career trajectories. The class also includes presentations from campus experts who offer important services that support Applied Physics graduate students in their successful degree completion.

APHY 588a, Modern Nanophotonics: Theory and Design  Owen Miller
This course is an introduction to modern nanophotonic theory and design. We introduce a broad range of mathematical and computational tools with which one can analyze, understand, and design for a diverse range of nanophotonic phenomena. The course is meant to be in the orthogonal complement of traditional courses working through Jackson's *Classical Electrodynamics*—we (mostly) avoid specialized high-symmetry cases in which Maxwell's equations can be solved exactly. Instead, our emphasis is on general mode, quasinormal-mode, and scattering-matrix descriptions, as well as surface- and volume-integral formulations that distill the essential physics of complex systems. The unique properties and trade-offs for a variety of computational methods, including finite-element, finite-difference, integral-equation, and modal-expansion (e.g., RCWA) approaches, comprise a significant portion of the latter half of the term. The robust open-source computational tools Meep, S4, and NLOpt are introduced early on, to be learned and utilized throughout the term. Prerequisites: undergraduate-level electromagnetism (e.g., APHY 322) and linear algebra (e.g., MATH 222 or 225); familiarity with any of Matlab/Python/Julia/etc., or a willingness to learn.
APHY 607b, Modern Topics in Optics and Quantum Electronics  Peter Rakich
This course provides a survey of modern topics involving integrated photonics, optomechanics, nonlinear optics, and laser physics for students interested in contemporary experimental optics research. Subjects include nonlinear wave phenomena, optomechanical interactions, phonon physics, light scattering, light emission and detection, cavities, systems of cavities, traveling-wave devices and interactions, perturbation theory, reciprocal and nonreciprocal systems, parametric interactions, laser oscillators and related technologies. Students are encouraged to explore these and related research topics through independent study and classroom presentations.

APHY 610b / PHYS 610b, Quantum Many-Body Theory  Leonid Glazman

APHY 628a / PHYS 628a, Statistical Physics II  Meng Cheng
An advanced course in statistical mechanics. Topics may include mean field theory of and fluctuations at continuous phase transitions; critical phenomena, scaling, and introduction to the renormalization group ideas; topological phase transitions; dynamic correlation functions and linear response theory; quantum phase transitions; superfluid and superconducting phase transitions; cooperative phenomena in low-dimensional systems.

APHY 633b / PHYS 633b, Introduction to Superconductivity  Yu He
The fundamentals of superconductivity, including both theoretical understandings of basic mechanism and description of major applications. Topics include historical overview, Ginzburg-Landau (mean field) theory, critical currents and fields of type II superconductors, BCS theory, Josephson junctions and microelectronic and quantum-bit devices, and high-Tc oxide superconductors.

APHY 634a / PHYS 634a, Mesoscopic Physics I  Michel Devoret
Introduction to the physics of nanoscale solid state systems, which are large and disordered enough to be described in terms of simple macroscopic parameters like resistance, capacitance, and inductance, but small and cold enough that effects usually associated with microscopic particles, like quantum-mechanical coherence and/or charge quantization, dominate. Emphasis is placed on transport and noise phenomena in the normal and superconducting regimes.

APHY 650a / PHYS 650a, Theory of Solids I  Leonid Glazman
APHY 675a / PHYS 675a, 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, nanophotonics, plasmonics, and metamaterials. Topics include propagation of light, reflection and refraction, guiding light, polarization, interference, diffraction, scattering, Fourier optics, and optical coherence.
APHY 676a / PHYS 676a, Introduction to Light-Matter Interactions  Peter Rakich
Optical properties of materials and a variety of coherent light-matter interactions are explored through the classical and quantum treatments. The role of electronic, phononic, and plasmonic interactions in shaping the optical properties of materials is examined using generalized quantum and classical coupled-mode theories. The dynamic response of media to strain, magnetic, and electric fields is also treated. Modern topics are explored, including optical forces, photonic crystals, and metamaterials; multi-photon absorption; and parametric processes resulting from electronic, optomechanical, and Raman interactions.

APHY 679a, Nonlinear Optics and Lasers
Properties and origins of the nonlinear susceptibility; Sum-freq, diff-freq and 2nd-harmonic generation; Intensity-dependent refractive index; Optical phase conjugation; Self-focusing, self-phase modulation, solitons; Stimulated light scattering; Fixed points, bifurcations; Amplification; Rate equations; Relaxation oscillations, frequency pulling; Hole burning; Q-switching; Semiconductor and DFB lasers; Mode-locking; Injection-locking; Intense-field NLO and QM laser theory (time permitting)

APHY 691a / PHYS 691a, Quantum Optics  Shruti Puri
Quantization of the electromagnetic field, coherence properties and representation of the electromagnetic field, quantum phenomena in simple nonlinear optics, atom-field interaction, stochastic methods, master equation, Fokker-Planck equation, Heisenberg-Langevin equation, input-output formulation, cavity quantum electrodynamics, quantum theory of laser, trapped ions, light forces, quantum optomechanics, Bose-Einstein condensation, quantum measurement and control.

APHY 990a or b, Special Investigations  Peter Schiffer
Faculty-supervised individual projects with emphasis on research, laboratory, or theory. Students must define the scope of the proposed project with the faculty member who has agreed to act as supervisor, and submit a brief abstract to the director of graduate studies for approval.