# APPLIED PHYSICS

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Courses given in Applied Physics have the subject code APPPHYS. For a complete list of subject codes, see Appendix.

The Department of Applied Physics offers qualified students with backgrounds in physics or engineering the opportunity to do graduate course work and research in the physics relevant to technical applications and natural phenomena. These areas include accelerator physics, biophysics, condensed matter physics, nanostructured materials, optoelectronics, photonics, quantum optics, space science and astrophysics, synchrotron radiation and applications. Student research is supervised by the faculty members listed above and also by various members of other departments such as Biological Sciences, Chemistry, Electrical Engineering, Materials Science and Engineering, Physics, SLAC, and faculty of the Medical School who are engaged in related research fields. Research activities are carried out in research laboratories including the Geballe Laboratory for Advanced Materials, the Edward L. Ginzton Laboratory, the Hansen Experimental Physics Laboratory, the Stanford Linear Accelerator Center, and the Stanford Synchrotron Radiation Laboratory.

The number of graduate students admitted to Applied Physics is limited. Applications should be received by January 3, 2006. Graduate students normally enter the department only in Autumn Quarter.

## GRADUATE PROGRAMS

Admission requirements for graduate work in Applied Physics include a bachelor's degree in physics or an equivalent engineering degree. Students entering the program from an engineering curriculum should expect to spend at least an additional quarter of study acquiring the background to meet the requirements for advanced degrees in Applied Physics.

## MASTER OF SCIENCE

The University's basic requirements for the master's degree are discussed in the "Graduate Degrees" section of this bulletin. The minimum requirements for the degree are 45 units, of which at least 39 units must be graduate-level courses in applied physics, engineering, mathematics, and physics. The required program consists of the following:

1. Courses in physics and mathematics to overcome deficiencies, if any, in undergraduate preparation.
2. Basic graduate courses (letter grade required):
   a) Advanced Mechanics—one quarter, 3 units: PHYSICS 210
   b) Electrodynamics—two quarters, 6 units: PHYSICS 220, 221
   c) Quantum Mechanics—two quarters, 6 units: PHYSICS 230, 231
3. 30 units of additional advanced courses in science and/or engineering. 15 of the 30 units may be any combination of advanced courses, Directed Study (APPPHYS 290), and 1-unit seminar courses, to complete the requirement of 45 units. At least 15 of these 30 units must be taken for a letter grade.
4. A final overall grade point average (GPA) of 3.0 (B) is required for courses used to fulfill degree requirements.

There are no department or University examinations, and a thesis is not required. If a student is admitted to the M.S. program only, but later wishes to change to the Ph.D. program, the student must apply to the department's Admissions Committee.

## DOCTOR OF PHILOSOPHY

The University's basic requirements for the Ph.D. (residency, dissertation, examination, and so on) are discussed in the "Graduate Degrees" section of this bulletin. The program leading to a Ph.D. in Applied Physics consists of course work, research, qualifying for Ph.D. candidacy, a research progress report, a University oral examination, and a dissertation as follows:

1. *Course Work:*
   a) Courses in Physics and Mathematics to overcome deficiencies, if any, in undergraduate preparation.
   b) Basic graduate courses* (letter grades required):
      1) Advanced Mechanics—one quarter: PHYSICS 210
      2) Statistical Physics—one quarter: PHYSICS 212
      3) Electrodynamics—two quarters: PHYSICS 220, 221
      4) Quantum Mechanics—two quarters: PHYSICS 230, 231
      5) Laboratory—one quarter: APPPHYS 207, 208, 304, 305; BIOSCI 232; EE 234, 410; MATSCI 171, 172, 173; PHYSICS 301.
   c) 18 units of additional advanced courses in science and/or engineering, not including Directed Study (APPPHYS 290), Dissertation Research (APPPHYS 390), and 1-unit seminar courses. Only 3 units at the 300 or above level may be taken on a satisfactory/no credit basis.
   d) 96 units of additional courses to meet the minimum residency requirement of 135. Directed study and research units as well as 1-unit seminar courses can be included.
   e) A final average overall grade point average (GPA) of 3.0 (B) is required for courses used to fulfill degree requirements.
   f) Students are normally expected to complete the specified course requirements by the end of their third year of graduate study.
2. *Research:* may be conducted in a science/engineering field under the supervision of a member of the Applied Physics faculty or appropriate faculty from other departments.
3. *Ph.D. Candidacy:* satisfactory progress in academic and research work, together with passing the Ph.D. Candidacy Qualifying Examination, qualifies the student to apply for Ph.D. candidacy which must be completed before the third year of graduate registration. The examination consists of a seminar on a suitable subject delivered by the student before the faculty academic adviser (or an approved substitute) and two other members of the faculty selected by the department.
4. *Research Progress Report:* normally before the end of the Winter Quarter of the fourth year of enrollment in graduate study at Stanford, the student arranges to give an oral research progress report of approximately 30 minutes, of which a minimum of 10 minutes should be devoted to questions from the Ph.D. reading committee.
5. *University Ph.D. Oral Examination*: consists of a public seminar in defense of the dissertation, followed by private questioning of the candidate by the University examining committee.
6. *Dissertation:* must be approved and signed by the Ph.D. reading committee.

* Requirements for item 1b may be totally or partly satisfied with equivalent courses taken elsewhere, pending the approval of the Graduate Study Committee.

### ASSISTANTSHIPS

Research assistantships are available for Ph.D. candidates. Contact the department for more information.

## COURSES

(AU) indicates that the course is subject to the University Activity Unit limitations (8 units maximum).

**APPPHYS 79Q. Energy Choices for the 21st Century**—Stanford Introductory Seminar. Preference to sophomores. Choices for meeting the future energy needs of the U.S. and the world. Basic physics of possible energy sources, technologies that might be employed, and related public policy issues. Trade-offs and societal impacts of different energy sources. Policy options for making rational choices for a sustainable world energy economy.
*3 units, Aut (Fox, Geballe)*

**APPPHYS 172. Physics of Solids I**—(Enroll in PHYSICS 172.)
*3 units, Spr (I. R. Fisher)*

**APPPHYS 192. Introductory Biophysics**—(For undergraduates; see 292.)
*3 units, Spr (Doniach) alternate years, not given 2006-07*

**APPPHYS 207,208. Laboratory Electronics**—Lecture/lab emphasizing analog and digital electronics for lab research. RC and diode circuits. Transistors. Feedback and operational amplifiers. Active filters and circuits. Pulsed circuits, voltage regulators, and power circuits. Precision circuits, low-noise measurement, and noise reduction techniques. Circuit simulation tools. Principles of synchronous demodulation and applications of lock-in amplifiers. Combinatorial and synchronous digital circuits. Design using programmable logic. Analog/digital conversion. Microprocessors and real time programming. Current lab interface protocols. Techniques commonly used for lab measurements. Development of student lab projects during the last three weeks of 208. Limited enrollment. Prerequisites: undergraduate device and circuit exposure.
**207.** *3 units, Win (Fox)*
**208.** *3 units (Fox) alternate years, given 2006-07*

**APPPHYS 210. Advanced Particle Mechanics**—(Enroll in PHYSICS 210.)
*3 units, Spr (Kallosh)*

**APPPHYS 211. Biophysics of Sensory Transduction**—(Enroll in BIOSCI 211.)
*4 units (S. Block) not given 2005-06*

**APPPHYS 212. Statistical Mechanics**—(Enroll in PHYSICS 212.)
*3 units, Spr (Fetter)*

**APPPHYS 213. Neuronal Biophysics**—(Enroll in BIOSCI 217.)
*4 units, Aut (Schnitzer)*

**APPPHYS 214. Randomness in the Physical World**—Topics include: random numbers, and their generation and application; disordered systems, quenching, and annealing; percolation and fractal structures; universality, the renormalization group, and limit theorems; path integrals, partition functions, and Wiener measure; random matrices; and optical estimation. Prerequisite: introductory course in statistical mechanics or analysis.
*3 units (Diaconis, S. Holmes, Kapitulnik, Shenker) alternate years, given 2006-07*

**APPPHYS 215. Numerical Methods for Physicists and Engineers**—Review of basic numerical techniques with additional advanced material: derivatives and integrals; linear algebra; linear least squares fitting, FFT and wavelets, singular value decomposition, linear prediction; optimization, nonlinear least squares, maximum entropy methods; deterministic and stochastic differential equations, Monte Carlo methods.
*3 units, Aut (Moler)*

**APPPHYS 216. X-Ray and VUV Physics**—Research and classical concepts in photon science. Photon-electron interactions; x-ray absorption and Compton scattering. X-ray spectroscopy; EXAFS, SEXAFS, edge structure, magnetic circular dichroism, and linear dichroism. Photoemission spectroscopy and many-electron effects: angle-resolved and integrated photoemission, resonance photoemission, spin-polarized photoemission. Photoelectron diffraction and holography. X-ray interactions with condensed matter: diffraction and scattering. Photon sources: synchrotron, wigglers, and undulators. Photon and electron detectors and analyzers. Prerequisite: familiarity with quantum mechanics.
*3 units (Shen) alternate years, given 2006-07*

**APPPHYS 217. Waves and Diffraction in Solids**—(Enroll in MATSCI 195/205.)
*3-4 units, Win (Wang)*

**APPPHYS 218. X-Ray and Neutron Scattering in the 21st Century**—Interaction of x-rays and neutrons with matter. Modern sources of radiation: synchrotrons, x-ray free electron lasers, and spallation neutron sources. Scattering formulae. Determination of molecular, crystal, and magnetic structures, and their associated charge, lattice, and magnetic excitations. Applications from condensed matter physics, materials science, biophysics, medicine, and the arts. Examples include thermal and quantum phase transitions, excitations and competing phases in high-temperature superconductors, materials under extreme pressure, structure of nanoparticles, proteins and water, computer-aided tomography, and nondestructive testing of art objects.
*3 units (Greven) alternate years, given 2006-07*

**APPPHYS 220. Classical Electrodynamics**—(Enroll in PHYSICS 220.)
*3 units, Aut (Church)*

**APPPHYS 221. Classical Electrodynamics**—(Enroll in PHYSICS 221.)
*3 units, Spr (Church)*

**APPPHYS 222. Applied Quantum Mechanics I**—(Enroll in EE 222.)
*3 units, Aut (Miller)*

**APPPHYS 223. Applied Quantum Mechanics II**—(Enroll in EE 223.)
*3 units, Win (Miller)*

**APPPHYS 226. Physics of Quantum Information**—Laws and concepts of quantum information science. Postulates of quantum mechanics: symmetrization postulate, quantum indistinguishability and multi-particle interference, commutation relation and quantum measurement, reduction postulate and impossibility of measuring, cloning and deleting a single wavefunction. Quantum information theory: von Neumann entropy, Holevo information and Schumacher data compression. Decoherence: Linbladian, quantum error correction, and purification of entanglement.
*3 units (Yamamoto) alternate years, given 2006-07*

**APPPHYS 227. Applications of Quantum Information**—Concepts and constituent technologies of quantum information systems. Quantum cryptography: single photon and entangled photon-pair-based quantum key distributions, quantum teleportation, quantum repeater. Quantum computer: Duetsch-Josza algorithm, Grover algorithm, Shor algorithm, quantum simulation, quantum circuits. Quantum hardwares: atomic physics, nuclear magnetic resonance, spintronics and quantum optics.
*3 units (Yamamoto) alternate years, given 2006-07*

**APPPHYS 230A. Quantum Mechanics**—(Enroll in PHYSICS 230.)
*3 units, Aut (Silverstein)*

**APPPHYS 230B. Quantum Mechanics**—(Enroll in PHYSICS 231.)
*3 units, Win (Shenker)*

**APPPHYS 231A. Introduction to Lasers**—(Enroll in EE 231.)
*3 units, Aut (Fejer)*

**APPPHYS 231B. Laser Dynamics**—(Enroll in EE 232.)
*3 units, Win (Fejer)*

**APPPHYS 232. Advanced Imaging Lab in Biophysics**—(Enroll in BIOSCI 132/232, BIOPHYS 232, MCP 232.)
*4 units, Spr (S. Block, Schnitzer, S. Smith, Stearns)*

**APPPHYS 248. Fundamentals of Noise Processes**—(Enroll in EE 248.)
*3 units, Aut (Yamamoto)*

**APPPHYS 268. Introduction to Modern Optics**—(Enroll in EE 268.)
*3 units, Aut (Byer)*

**APPPHYS 270. Magnetism and Long Range Order in Solids**—Co-operative effects in solids, with an emphasis on experimental results for archetypical materials. Topics include the origin of magnetism in solids, phase transitions and long range order, measurement of thermodynamic and transport properties, elements of sample preparation and crystal growth, crystal electric field effects, ferromagnetism, antiferromagnetism, density waves, and superconductivity. Prerequisite: PHYSICS 172 or MATSCI 209, or equivalent introductory condensed matter physics course. GER:DB-NatSci

*3 units (Fisher) not given 2005-06*

**APPPHYS 271. Concepts in Condensed Matter Physics**—(Enroll in PHYSICS 173B.)

*1 unit (Beasley) not given 2005-06*

**APPPHYS 272. Solid State Physics I**—The properties of solids. Theory of free electrons, classical and quantum. Crystal structure and methods of determination. Electron energy levels in a crystal: weak potential and tight-binding limits. Classification of solids: metals, semiconductors, and insulators. Types of bonding and cohesion in crystals. Lattice dynamics, phonon spectra, and thermal properties of harmonic crystals. Pre- or corequisites: PHYSICS 120 and 121; and PHYSICS 130 and 131, or equivalents.

*3 units, Win (Manoharan)*

**APPPHYS 273. Solid State Physics II**—Electronic structure of solids. Electron dynamics and transport. Semiconductors and impurity states. Surfaces. Dielectric properties of insulators. Electron-electron, electron-phonon, and phonon-phonon interactions. Anharmonic effects in crystals. Electronic states in magnetic fields and the quantum Hall effect. Magnetism, superconductivity, and related many-particle phenomena. Prerequisite: 272.

*3 units, Spr (Manoharan)*

**APPPHYS 275. Probing the Nanoscale**—Theory, operation, and applications of nanoprobes of interest in physics and materials science. Lectures by experts. Topics include scanning tunneling microscopy, spectroscopy, and potentiometry; atomic manipulation; scanning magnetic sensors and magnetic resonance; scanning field-effect gates; scanning force probes; and ultra-near-field optical scanning.

*3 units, Win (Beasley)*

**APPPHYS 280. Phenomenology of Superconductors I**—Applications based on superconductivity as a phase-coherent macroscopic quantum phenomena. Topics include the superconducting pair wave function, London and Ginzburg Landau theories, their physical content, the Josephson effect and superconducting quantum interference devices, s- and d-wave superconductivity, the response of superconductors to currents, magnetic fields, and rf electromagnetic radiation.

*3 units, Aut (Kapitulnik)*

**APPPHYS 281. Phenomenology of Superconductors II**—Continuation of 280. Topics include vortex states of matter, collective pinning, fluctuation effects, effects of dimensionality, the Kosterlitz-Thouless transition, Josephson junction arrays, quantum effects, and the superconductor/insulator transition.

*3 units (Beasley) not given 2005-06*

**APPPHYS 290. Directed Studies in Applied Physics**—Special studies under the direction of a faculty member for which academic credit may properly be allowed. May include lab work or directed reading.

*1-15 units, Aut, Win, Spr, Sum (Staff)*

**APPPHYS 291. Practical Training**—Opportunity for practical training in industrial labs. Arranged by student with research adviser's approval. Summary of activities required.

*3 units, Aut, Win, Spr, Sum (Staff)*

**APPPHYS 292. Introductory Biophysics**—(Same as 192.) For advanced undergraduates or beginning graduate students. Quantitative models used in molecular biophysics. The relation of structure to function. Chemical equilibria, cooperativity, and control: elementary statistical mechanics, affinity plots, allostery, models of hemoglobin-oxygen binding, bacterial chemotaxis. Macromolecular conformations: polymer chain models, protein folding, taxonomy of globular proteins, general principles of sequence selection. Chemical kinetics. Multiple barriers: CO-myoglobin kinetics, ion diffusion through channels and ion selectivity, spectroscopy of ion channels-acetylcholine receptor. Supramolecular kinetics: conversion of chemical energy to mechanical force, myosin and kinesin, actin polymers. Nerve impulse propagation: membrane potentials, voltage sensitive ion gates, Hodgkin Huxley equations, propagation of the nerve impulse.

*3 units, Spr (Doniach) alternate years, not given 2006-07*

**APPPHYS 304. Lasers Laboratory**—Theory and practice. Theoretical and descriptive background for lab experiments, detectors and noise, and lasers (helium neon, beams and resonators, argon ion, cw dye, titanium sapphire, semiconductor diode, and the Nd:YAG). Measurements of laser threshold, gain, saturation, and output power levels. Laser transverse and axial modes, linewidth and tuning, Q-switching and modelocking. Limited enrollment. Prerequisites: EE 231 and 232, or consent of instructor.

*3 units, Win (Byer)*

**APPPHYS 305. Nonlinear Optics Laboratory**—Laser interaction with matter. Laser devices provide radiation to explore the linear and nonlinear properties of matter. Experiments on modulation, harmonic generation, parametric oscillators, modelocking, stimulated Raman and Brillouin scattering, coherent anti-Stokes scattering, other four-wave mixing interactions such as wavefront conjugation and optical bistability. Optical pumping and spectroscopy of atomic and molecular species. Limited enrollment. Prerequisites: 304, EE 231 and 232, or consent of instructor.

*3 units, Spr (Byer) alternate years, not given 2006-07*

**APPPHYS 324. Introduction to Accelerator Physics**—Dynamics of a beam of particles from first principles. Transverse dynamics description with Courant-Snyder matrix formalism. Longitudinal dynamics description with phase space Hamiltonian. Effects of synchrotron radiation on beam dynamics. Advanced topics of nonlinear dynamics and collective instability effects. Emphasis is on physical concepts and practical application examples. Prerequisites: undergraduate electromagnetism and mathematical physics.

*3 units, Win (Chao, Ruth) alternate years, not given 2006-07*

**APPPHYS 346. Introduction to Nonlinear Optics**—(Enroll in EE 346.)

*3 units, Spr (S. Harris)*

**APPPHYS 366. Introduction to Fourier Optics**—(Enroll in EE 366.)

*3 units (Hesselink) alternate years, given 2006-07*

**APPPHYS 372. Condensed Matter Theory I**—Fermi liquid theory, many-body perturbation theory, response function, functional integrals, interaction of electrons with impurities.

*3 units (Staff) not given 2005-06*

**APPPHYS 373. Condensed Matter Theory II**—Superfluidity and superconductivity. Quantum magnetism. Prerequisite: 372.

*3 units (Staff) not given 2005-06*

**APPPHYS 377. Literature of Condensed Matter Physics**—Discoveries and experiments in condensed matter physics in the past 15 years. Topics: sliding charge density waves in layer compounds, the first pressure-induced Mott transition and organic superconductor, discovery of superfluid 3He, quasicrystals, the Sharvin effect, the quantum Hall effect, and reentrant superconductivity. Journal club format; student presentations.

*3 units, Aut (Shen) alternate years, not given 2006-07*

**APPPHYS 383. Introduction to Atomic Processes**—Atomic spectroscopy, matrix elements using the Coulomb approximation, summary of Racah algebra, oscillator and line strengths, Einstein A coefficients. Radiative processes, Hamiltonian for two- and three-state systems, single- and multi-photon processes, linear and nonlinear susceptibilities, density matrix, brightness, detailed balance, and electromagnetically induced transparency. Inelastic collisions in the impact approximation, interaction potentials, Landau-Zener formulation. Continuum processes, Saha equilibrium, autoionization, and recombination.

*3 units, Aut (S. Harris) alternate years, not given 2006-07*

**APPPHYS 387. Quantum Optics and Measurements**—Postulates in quantum mechanics and quantum optics: Heisenberg's uncertainty principle, von Newmann's projection hypothesis, quantum non-demolition measurements, quantum states of light, cavity quantum electrodynamics, nonlocality and quantum entanglement. Second quantization of bosonic and fermionic fields; Glauber, Fock, Dicke, and Bloch states, first- and second-order coherence, quantum interference. Reservoir theory of open systems: Markoff and Born approximations, density operator master, Fokker-Planck, quantum Langevin, stochastic differential equations, quantum Monte-Carlo wavefunction method.

*3 units, Win (Yamamoto) alternate years, not given 2006-07*

**APPPHYS 388. Mesoscopic Physics and Nanostructures**—Optical properties of semiconductor nanostructures: interband and intraband optical transitions, excitons and polaritons, semiconductor Bloch equations, bosonization, exciton BEC, exciton laser. Transport properties in mesoscopic and atomic systems: electron optics versus photon optics, Landauer-Büttiker formula, noise in diffusive and dissipative transport, nonequilibrium Green's function, electron entanglement, Coulomb blockade, single electronics, and spin dynamics in semiconductor quantum dots. Student presentations on assigned topics.

*3 units, Spr (Yamamoto) alternate years, not given 2006-07*

**APPPHYS 390. Dissertation Research**

*1-15 units, Aut, Win, Spr, Sum (Staff)*

**APPPHYS 392. Topics in Molecular Biophysics**—Concepts from statistical mechanics applied to contemporary molecular biology: allosteric transitions; protein folding; molecular recognition; actin polymers and gels; molecular motors; lipids and membrane proteins; ion channels. Some of the basic models used to quantitate fundamental biomolecular functions. Prerequisites: elementary statistical mechanics and chemical kinetics.

*3 units (Doniach) alternate years, given 2006-07*

**APPPHYS 453A. Topics in Accelerator Physics: The Linac Coherent Light Source**—Properties of synchrotron radiation. Free electron lasers. Self-amplified spontaneous emission. Computed and measured properties of SASE free electron lasers. Design considerations for the Linac Coherent Light Source. Overview of applications of the LCLS as a research instrument. Survey of free electron laser facilities being designed worldwide. May be repeated for credit.

*3 units, Spr (Galayda)*

**APPPHYS 470. Condensed Matter Seminar**—Current research and literature; offered by faculty, students, and outside specialists. May be repeated for credit.

*1 unit, Aut, Win, Spr (Staff)*

**APPPHYS 473A. Condensed Matter Physics**—Students undertake background study prior to each weekly seminar offered through 470 as an introduction to topics of contemporary interest in condensed matter physics, critique each seminar for success in oral communication, and present a one-hour seminar on a contemporary topic for critique by the class. Corequisite: 470.

*2 units (Staff) not given 2005-06*

**APPPHYS 483. Optics and Electronics Seminar**—Current research topics in lasers, quantum electronics, optics, and photonics by faculty, students, and invited speakers. May be repeated for credit.

*1 unit, Aut, Win, Spr (Staff)*