PHYSICS
(AS) {PHYS}

005. The World of Physics. (M) Physical World Sector. All classes. Prerequisite(s): Entrance credit in algebra and trigonometry.

An introduction to the physical theories of the mechanical universe. The courses focuses on the development and principles of Newtonian mechanics, relativity and the relativistic mechanics of Einstein, and the quantum mechanics needed to describe atomic and nuclear phenomena. This course cannot be taken for credit by a student also receiving credit for PHYS 008, 009, or any physics course numbered 100 or greater.

008. Physics for Architects I. (I) Physical World Sector. All classes. Prerequisite(s): Entrance credit in algebra and trigonometry.

Introductory course for students in architecture stressing statics, but also covering such topics as fluid flow, waves, electricity, and energy. This course cannot be taken for credit by a student also receiving credit for any physics course numbered 100 or greater.

016. Energy, Oil, and Global Warming. (C) Natural Science & Mathematics Sector. Class of 2010 and beyond. Prerequisite(s): Algebra and Trigonometry. May be counted as Science Studies for students in Class of 2009 and prior. Target audience: Non-science majors (although science/engineering students are welcome).

The developed world's dependence on fossil fuels for energy production has extremely undesirable economic, environmental, and political consequences, and is likely to be mankind's greatest challenge in the 21st century. We describe the physical principles of energy, its production and consumption, and environmental consequences, including the greenhouse effect. We will examine a number of alternative modes of energy generation - fossil fuels, biomass, wind, solar, hydro, and nuclear - and study the physical and technological aspects of each, and their societal, environmental and economic impacts over the construction and operational lifetimes. No previous study of physics is assumed.

021. Physics of Music. (M) May be counted as a General Requirement Course in Physical World. Class of 2009 & prior only. Freshman seminar.

This seminar will be an experimental inquiry into physics of music. The concepts of simple harmonic oscillation, damping, coupling, resonance, and harmonic analysis will be applied to a laboratory study of selected musical instruments, the voice, and rooms. Attention will be given to driving mechanisms, instabilities, sound radiation, transients, harmonic series. This course cannot be taken for credit by a student who has already received credit for PHYS 008, 009, or any physics course numbered 100 or greater.

050. Physics Laboratory I. (C) Prerequisite(s): AP score of 5 on the Physics B or Physics C - Mechanics exam, or transfer credit for PHYS 91 or PHYS 93. Course carries .5 course unit and student receives grade. Permit required.

Experiments in classical mechanics.

051. Physics Laboratory II. (C) Prerequisite(s): AP score of 5 on the Physics B or Physics C - Electricity and Magnetism exam, or transfer credit for PHYS 92 or PHYS 94. PHYS 050. Course carries .5 course unit and student receives grade. Permit required.

Experiments in electromagnetism and optics.

L/L 101. General Physics: Mechanics, Heat and Sound. (C) Physical World Sector. All classes. Prerequisite(s): Entrance credit in algebra and trigonometry, and a background in calculus. Corequisite(s): PHYS 101 LAB. Credit is awarded for only one of the following courses: PHYS 101, PHYS 150, or PHYS 170. Students with AP or Transfer Credit for PHYS 91 or PHYS 93 who complete PHYS 101 will thereby surrender the AP or Transfer Credit.

An introduction to the classical laws of motion requiring a background in calculus. Suggested for students in a pre-health program.

L/L 102. General Physics: Electromagnetism, Optics, and Modern Physics. (C) Physical World Sector. All classes. Prerequisite(s): PHYS 101. Corequisite(s): PHYS 102 LAB. Credit is awarded for only one of the following courses: PHYS 102, PHYS 151, or PHYS 171. Students with AP or Transfer Credit for PHYS 92 or PHYS 94 who complete PHYS 102 will thereby surrender the AP or Transfer Credit.
A continuation of PHYS 101 emphasizing an introduction to classical electricity and magnetism, relativity theory, optics, and the quantum theory of matter, requiring a background in calculus. Suggested for students in a pre-health program.

137. Community Physics Initiative. (A) May be counted as a General Requirement Course in Science studies. Class of 2009 & prior only.

This is an Academically Based Community Service Course (ABCS). It will be aligned to the Philadelphia School District curriculum in introductory physics at University City High School (UCHS). The UCHS curriculum roughly parallels the contents of first semester introductory physics (non-calculus) at Penn.

140. Principles of Physics I (without laboratory). (C) Corequisite(s): MATH 104. For Engineering students whose course of study does not require a physics laboratory course.

Classical laws of motions; interactions between particles; conservation laws and symmetry principles; particle and rigid body motion; gravitation, harmonic motion.

141. Principles of Physics II (without laboratory). (C) Prerequisite(s): PHYS 140. Corequisite(s): MATH 114. For Engineering students whose course of study does not require a physics laboratory course.

Electric and magnetic fields; Coulomb's, Ampere's, and Faraday's laws; Maxwell's equations; emission, propagation, and absorption of electromagnetic radiation; interference, reflection, refraction, scattering, and diffraction phenomena.

L/L 150. Principles of Physics I: Mechanics and Wave Motion. (C) Physical World Sector. All classes. Corequisite(s): MATH 104, PHYS 150 LAB. Credit is awarded for only one of the following courses: PHYS 101, PHYS 150, or PHYS 170. Students with AP or Transfer Credit for PHYS 91 or PHYS 93 who complete PHYS 150 will thereby surrender the AP or Transfer Credit.

Recommended for science majors and engineering students. Classical laws of motion; interactions between particles; conservation laws and symmetry principles; particle and rigid body motion; gravitation, harmonic motion.

L/L 151. Principles of Physics II: Electromagnetism and Radiation. (C) Physical World Sector. All classes. Prerequisite(s): PHYS 150 or PHYS 170. Corequisite(s): MATH 114, PHYS 151 LAB. Credit is awarded for only one of the following courses. PHYS 102, PHYS 151, or PHYS 171. Students with AP or Transfer Credit for PHYS 92 or PHYS 94 who complete PHYS 151 will thereby surrender the AP or Transfer Credit.
Electric and magnetic fields; Coulomb's, Ampere's, and Faraday's laws; Maxwell's equations; emission, propagation, and absorption of electromagnetic radiation; interference, reflection, refraction, scattering, and diffraction phenomena.

SM 170. Honors Physics I: Mechanics and Wave Motion. (A) Physical World Sector. All classes. Prerequisite(s): MATH 104 or permission of the instructor. Corequisite(s): MATH 114 or permission of instructor. Benjamin Franklin Seminar. Credit is awarded for only one of the following courses: PHYS 101, 150, or PHYS 170. Students with AP or Transfer Credit for PHYS 91 or PHYS 93 who complete PHYS 170 will thereby surrender the AP or TransferCredit.

This course parallels and extends the content of PHYS 150, at a significantly higher mathematical level. Recommended for well-prepared students in engineering and the physical sciences, and particularly for those planning to major in physics. Classical laws of motion: interaction between particles; conservation laws and symmetry principles; rigid body motion; noninertial reference frames; oscillations.

SM 171. Honors Physics II: Electromagnetism and Radiation. (B) Physical World Sector. All classes. Prerequisite(s): MATH 114 and PHYS 150 or PHYS 170, or permission of instructor. Corequisite(s): MATH 240 or permission of instructor. Benjamin Franklin Seminar. Credit is awarded for only one of the following courses: PHYS 102, PHYS 151, or PHYS 171. Students with AP or Transfer Credit for PHYS 92 or PHYS 94 who complete PHYS 171 will thereby surrender the AP or Transfer Credit.

This course parallels and extends the content of PHYS 151, at a somewhat higher mathematical level. Recommended for well-prepared students in engineering and the physical sciences, and particularly for those planning to major in physics. Electric and magnetic fields; Coulomb's, Ampere's, and Faraday's laws; special relativity; Maxwell's equations, electromagnetic radiation.

230. Principles of Physics III: Thermal Physics and Waves. (A) Prerequisite(s): PHYS 150/151 or PHYS 170/171 and MATH 104, MATH 115. Corequisite(s): MATH 240.

Elementary thermodynamics and statistical physics including heat engines and the Maxwell-Boltzmann distribution, independent and forced harmonic motion, coupled oscillators, normal modes, longitudinal and transverse sound and light waves, interference and diffraction, and elementary Fourier analysis and the uncertainty principle.

240. Principles IV: Modern Physics. (B) Prerequisite(s): PHYS 151 or 171. Corequisite(s): MATH 240.

Special relativity, an introduction to the principles of quantum mechanics, properties of electrons, protons, neutrons, and the elements of atomic structure and nuclear structure. Electromagnetic radiation and photons; interaction of photons with electrons, atoms, and nuclei.

L/L 250. Principles of Physics III: Modern Physics. (B) Prerequisite(s): PHYS 150/151 or PHYS 170/171. Corequisite(s): MATH 240. PHYS 250 students take a two-hour lab.

Special relativity, an introduction to the principle of quantum mechanics, properties of electrons, protons, neutrons, and the elements of atomic structure and nuclear structure. Electromagnetic radiation and photons; interaction of photons with electrons, atoms, and nuclei.

280. (BCHE280) Physical Models of Biological Systems. (A) Prerequisite(s): PHYS 101 (or higher), MATH 104 and (MATH 114 or MATH 115). Recommended: previous or concurrent PHYS 102; basic background in chemistry and biology.

Classic case studies of successful reductionistic models of complex phenomena, emphasizing the key steps of (1) making estimates, often based on dimensional analysis, (2) using them to figure out which physical variables and phenomena will be most relevant to a given system, and which may be disregarded, and (3) finding analogies to purely physical systems whose behavior is already known. The cases studied involve basic biological processes, mainly at the molecular and cellular level, in the light of ideas from physics. Topics may include entropic forces, free energy transduction at the molecular level, the structure of biopolymers, molecular motors, pattern formation (oscillation and morphogenesis), immune response, nerve impulses and neural computing, and other forms of signal transduction.

295. Introduction to Research in Physics and Astronomy. (M) Prerequisite(s): PHYS 150/151 or PHYS 170/171 or PHYS 101/102. Benjamin Franklin Seminar.

This course will provide an introduction to current research performed by faculty in the Department of Physics and Astronomy. It will be particularly appropriate for sophomore or junior physics majors interested in participating in physics research; it will also be of interest to other science- or engineering-oriented students who want to learn more about current topics in physics. Grading will be based on attendance at seminars presented by faculty, homework assignments, and a term paper.

299. Independent Study. (C) Repetitive credit.

Special projects and independent study under the direction of faculty member.

351. Analytical Mechanics. (B) Prerequisite(s): PHYS 150/151 or PHYS 170/171, MATH 104/114, and MATH 240, or permission of instructor.

An intermediate course in the statics and dynamics of particles and rigid bodies. Langrangian dynamics, central forces, non-inertial reference frames, and rigid bodies.

361. (PHYS561) Electromagnetism I: Electricity and Potential Theory. (A) Prerequisite(s): PHYS 151 or 171, and MATH 241.

An intermediate course. Electrostatic fields and potentials, dielectrics, and direct currents.

362. (PHYS562) Electromagnetism II: Magnetism, Maxwell's Equations, and Electromagnetic Waves. (B) Prerequisite(s): PHYS 361.

A continuation of PHYS 361. Magnetic fields and potentials, electromagnetic induction, Maxwell's equations, electromagnetic waves, and radiation.

L/L 364. (PHYS564) Measurements Laboratory. (A) Prerequisite(s): PHYS 151 or 171.

Introduction to the electronic techniques of modern physical measurements. Recommended for undergraduates planning independent research projects in experimental physics.

401. (PHYS581) Thermodynamics and the Introduction to Statistical Mechanics and Kinetic Theory. (A) Prerequisite(s): PHYS 240 or 250.

Temperature, entropy and generalized potentials, phase transitions, and introduction to ensemble theory and distribution functions.

411. (PHYS511) Introduction to Quantum Mechanics I. (A) Prerequisite(s): PHYS 150 or 170, 240 or 250, and MATH 241.

An introduction to the principles of quantum mechanics designed for physics majors and graduate students in physics-related disciplines. The Schrodinger equation operator formalism, central field problem, angular momentum, and spin. Application to one-dimensional and central field problems.

412. (PHYS512) Introduction to Quantum Mechanics II. (B) Prerequisite(s): PHYS 411.

Perturbation theory, variational principle, application of the quantum theory to atomic, molecular, and nuclear systems, and their interaction with radiation.

414. Laboratory in Modern Physics. (B) Prerequisite(s): PHYS 364 and 411.

Supervised experiments in modern physics.

421. (PHYS529) Modern Optics. (J) Prerequisite(s): PHYS 240 or 250 and 362, or permission of instructor.

Interaction of light with matter. Interference and diffraction, absorption and dispersion, stimulated emission and coherence, spectroscopy, non-linear processes.

432. Introduction to Nuclear and Elementary Particle Physics. (M) Prerequisite(s): PHYS 411 or permission of instructor.

An introduction to nuclear forces, the structure of atomic nuclei, nuclear reactions elementary particles (photons, leptons, hadrons, quarks) and their interactions, and the unification of the fundamental forces.

499. Senior Honor Thesis. (C) Prerequisite(s): PHYS 412 and 414.

Experimental and theoretical research projects in various areas of physics planned by student in consultation with a member of faculty. A written thesis and an oral presentation and defense are required.

500. (MATH594) Mathematical Methods of Physics. (C)
A discussion of those concepts and techniques of classical analysis employed in physical theories. Topics include complex analysis. Fourier series and transforms, ordinary and partial equations, Hilbert spaces, among others.

501. Introduction to Research. (C) Taken by all first-year graduate students. This is a required seminar that does not carry credit or a grade.

Introduction to research in particle, nuclear, condensed matter and astrophysics. Selected current topics from journals.

503. (ASTR525) General Relativity and Cosmology. (M)

This is a graduate level, introductory course in general relativity and modern cosmology. The basics of general relativity will be covered with a view to understanding cosmology and carrying out calculations relevant to the expanding universe and perturbations in it. Some of the key topics in modern cosmology will be covered -- these include the cosmic microwave background, large-scale structure, gravitational lensing and dark energy. The current cosmological model and open questions driving research will be discussed briefly in connection with these topics.

505. Introduction to Cosmology. (M) Prerequisite(s): Graduate standing in physics or permission of instructor.

Introduction to physical cosmology emphasizing recent ideas on the very early evolution of the universe. The course will introduce standard big bang cosmology, new theories of the very early universe, and the key observations that have tested and will be testing these ideas. No prior knowledge of astrophysics, cosmology, general relativity, or particle physics will be assumed, although aspects of each will be introduced as part of the course. The course is intended for graduate students and advanced undergraduates.

514. Mechanics, Fluids, Chaos. (B)

A general introduction to linear and nonlinear dynamical systems with an emphasis on astrophysical systems. Lagrangian and Hamiltonian formulations. Celestial mechanics. Equilibria and stability. Orbits. Resonances. Galactic dynamics. Intended for graduate students and advanced undergraduates.

516. Electromagnetic Phenomena. (B) Nelson.

Survey of electrodynamics, focusing on applications to research done in the Department. Topics include mathematical structure and relativistic invariance properties of Maxwell equations, tensor methods, and the generation and scattering of radiation, in vacuum and in materials. Applications vary from year to year but include optical manipulation, astrophysical phenomena, and the generalizations from Maxwell's theory to those of other fundamental interactions (strong, electroweak, and gravitational forces).

517. Particle Cosmology. (C) Khoury.

This introduction to cosmology will cover standard big bang cosmology, formation of large-scale structure, theories of the early universe and their observational predictions, and models of dark energy. It is intended for graduate students or advanced undergraduates. No prior knowledge of general relativity or field theory will be assumed, although aspects of each will be introduced as part of the course.

518. Introduction to Condensed Matter Physics. (B) Prerequisite(s): Undergraduate training in quantum mechanics and statistical thermodynamics.

An introduction to condensed matter physics designed primarily for advanced undergraduate and graduate students desiring a compact survey of the field. Band theory of solids, phonons, electrical magnetic and optical properties of matter, and superconductivity.

521. Advanced Laboratory. (C)

Directed experiments in classical and modern physics designed to acquaint the student with modern laboratory instrumentation and techniques.

522. Introduction to Elementary Particle Physics. (M) Williams. Prerequisite(s): Permission of instructor required.

An introduction to elementary particles (photons, leptons, hadrons, quarks), their interactions, and the unification of the fundamental forces.

525. Special Projects. (C) Repetitive credit.

Special projects under the direction of a faculty member.

526. Astrophysical Radiation. (M)

This is a course on the theory of the interaction of light and matter designed primarily for graduate and advanced undergraduate students to build the basic tools required to do research in astrophysics. Topics to be discussed include structure of single- and multi-electron atoms, radiative and collisional processes, spectral line formation, opacity, radiation transfer, analytical and numerical methods, and a selection of applications in astrophysics based on student research interest.

528. Introduction to Liquid Crystals. (C)

Overview of liquid crystalline phases, their elasticity, topology, and dynamics.

530. Modern Optical Physics and Spectroscopy. (K) Prerequisite(s): Working knowledge of electricity and magnetism and quantum mechanics. Graduate level course designed for beginning or intermediate graduate students in physics, but it is likely to be of use to a broader community including beginning graduate students whose research involves light scattering in electrical engineering, chemistry, and biophysics, and advanced undergraduates.

Introduction to contemporary optics. Topics include propagation and guiding of light waves, interaction of electromagnetic radiation with matter, lasers, non-linear optics, coherent transcient phenomena, photon correlation spectroscopies and photon diffusion.

531. Quantum Mechanics I. (A) Prerequisite(s): A minimum of one semester of quantum mechanics at the advanced undergraduate level.

Wave mechanics, complementarity and correspondence principles, semi-classical (WKB) approximation, bound state techniques, periodic potentials, angular momentum, scattering theory, phase shift analysis, and resonance phenomena.

532. Quantum Mechanics II. (B) Prerequisite(s): PHYS 531.

Spin and other two dimensional systems, matrix mechanics, rotation group, symmetries, time independent and time dependent perturbation theory, and atomic and molecular systems.

533. Topics in Cosmology. (M)

This course aims to survey three or four topics of current research interest in cosmology, mostly at the level of review articles. The topics will be covered in greater depth and with more connections to ongoing research than the introductory cosmology course, ASTR 525. The course will be largely accesible to first and second year graduate students. Some exposure to cosmology and general relativity will be helpful but the first two weeks will attempt to bridge that gap. The topic selection will be done in part with input from the students. For the Fall 2004 semester, Dark Energy will be the first topic, Nonlinear Dynamics the likely second topic and Gravitational Lensing (focus on strong lensing) is a possible third topic. A few short problem sets and a presentation/write-up on a topic of interest, based on a review article or selected papers, will make up the course requirement.

L/L 564. (PHYS364) Measurements Laboratory. (A)

Introduction to the electronic techniques of modern physical measurements. Recommended for undergraduates planning independent research projects in experimental physics.

580. (BCHE580) Biological Physics. (H) Prerequisite(s): PHYS 401 or CHEM 221-222 (may be taken concurrently) or familiarity with basic statistical mechanics and thermodynamics. Recommended: Basic background in chemistry and biology.

A survey of basic biological processes at all levels of organization (molecule, cell, organism, population) in the light of simple ideas from physics. Both the most ancient and the most modern physics ideas can help explain emergent aspects of life, i.e., those which are largely independent of specific details and cut across many different classes of organisms. Topics may include thermal physics, entropic forces, free energy transduction, structure of biopolymers, molecular motors, cell signaling and biochemical circuits, nerve impulses and neural computing, populations and evolution, and the origins of life on Earth and elsewhere.

581. (PHYS401) Thermodynamics. (A)

582. (BE 580) Medical Radiation Engineering. (M)

This course in medical radiation physics investigates electromagnetic and particulate radiation and its interaction with matter. The theory of radiation transport and the basic concept of dosimetry will be presented. The principles of radiation detectors and radiation protection will be discussed.

601. Introduction to Field Theory. (A)

Elementary relativistic quantum field theory of scalar, fermion, and Abelian gauge fields. Feynman Diagrams.

611. Statistical Mechanics. (A) Prerequisite(s): PHYS 401, 531, or equivalent.

Introduction to the canonical structure and formulation of modern statistical mechanics. The thermodynamic limit. Entropic and depletion forces. Gas and liquid theory. Phase transitions and critical phenomena. The virial expansion. Quantum statistics. Path integrals, the Fokker-Planck equation and stochastic processes.

622. Introduction to Elementary Particle Physics. (M) Prerequisite(s): PHYS 601.

Introduction to the phenomenology of elementary particles, strong and weak interactions, symmetries.

632. Relativistic Quantum Field Theory. (M) Prerequisite(s): PHYS 601.

Advanced topics in field theory, including renormalization theory.

633. Relativistic Quantum Field Theory. (M) Prerequisite(s): PHYS 632.

A continuation of PHYS 632, dealing with non-Abelian gauge theories.

654. (MATH694) Anomalies in Quantum Field Theory and Superstrings: A Topological Approach. (M)

This course is designed for students in both the Physics and Mathematics Departments who are interested in mathematical physics, particularly as it applies to quantum field theory, relativity and superstrings. We will focus on the theory of anomalies from two distinct points of view.

655. (MATH695) Geometry and String Theory. (M)

The goal of the course is to introduce students, post-docs and faculty to the mathematics and physics associated with the recent advances in field theory and superstring theory. We will introduce, and use, relatively sophisticated mathematical techniques, such as index theorems, elliptic fibrations and vector bundle theory. These will be applied to important physics topics such as anomalies and F-theory/M-theory duality, with the goal of giving the student high-level familiarity with formal superstring theory.

656. (MATH696) Topics in Mathematical Physics and String Theory. (M) Staff.

This interdisciplinary course discusses advanced topics in mathematical physics. Topics may include elliptic operators, heat kernels, complexes and the Atiyah-Singer index theorem, Feynman graphs and anomalies, computing Abelian and non-Abelian anomalies, and the relation of anomalies to the index theorem.

657. (MATH697) Topics in Mathematical Physics and String Theory. (M)

Continuation of PHYS 656. Topics may include the family index theorem, equivariant cohomology and loop spaces, the homological algebra of BRST invariance and the Wess-Zumino consistency condition, the descent equations, and worldsheet anomalies in string theory.

661. Solid State Theory I. (M)

This course is intended to be an introductory graduate course on the physics of solids, crystals and liquid crystals. There will be a strong emphasis on the use and application of broken and unbroken symmetries in condensed matter physics. Topics covered include superconductivity and superfluidity.

662. Solid State Theory II. (M)

A continuation of PHYS 661.

682. Elementary Particle Theory. (M)

Gauge theories, the standard model of strong and electroweak interactions, extended electroweak models, unified theories and their theoretical, experimental, and cosmological implications. This course is intended to bring students to the level of current research in elementary particle physics.

696. Advanced Topics in Theoretical Physics. (M)

990. Masters Thesis. (C)

995. Dissertation. (C)

999. Independent Study. (C)