PHYSICS (PHYS)

PHYS 008 Physics for Architects I
An introduction to the classical laws of mechanics, including static equilibrium, elasticity, and oscillations, with emphasis on topics most relevant to students in architecture. Credit is awarded for only one of the following courses: PHYS 008, PHYS 101, PHYS 150, or PHYS 170. Students with AP or Transfer Credit for PHYS 091 or 093 who complete PHYS008 will thereby surrender the AP or Transfer Credit.
For BA Students: Physical World Sector
Course offered fall; odd-numbered years
Prerequisites: Entrance credit in algebra and trigonometry.
Activity: Lecture
1 Course Unit
Notes: Credit is awarded for only one of the following courses: PHYS 008, PHYS 101, PHYS 150, or PHYS 170. Students with AP or Transfer Credit for PHYS 091 or 093 who complete PHYS 008 will thereby surrender the AP or Transfer Credit.

PHYS 009 Physics for Architects II
Briefly reviews Newton's laws, then introduces waves, sound, light, fluids, heat, electricity, magnetism, and circuits, with emphasis on topics most relevant to students in architecture. Illustrates physics principles using examples drawn from architecture. Students with a strong high-school physics background may take PHYS 008 and PHYS 009 in either order. Credit is awarded for only one of the following courses: PHYS 009, PHYS 102, PHYS 151, or PHYS 171. Students with AP or Transfer Credit for PHYS 092 or 094 who complete PHYS008 will thereby surrender the AP or Transfer Credit.
For BA Students: Physical World Sector
Course offered fall; even-numbered years
Activity: Lecture
1 Course Unit
Notes: Credit is awarded for only one of the following courses: PHYS 009, PHYS 102, PHYS 151, or PHYS 171. Students with AP or Transfer Credit for PHYS 092 or 094 who complete PHYS 008 will thereby surrender the AP or Transfer Credit.

PHYS 010 Energy, Oil, and Global Warming
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.
For BA Students: Natural Science and Math Sector
One-term course offered either term
Prerequisites: Algebra and Trigonometry
Activity: Lecture
1 Course Unit
Notes: 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).

PHYS 050 Physics Laboratory I
Experiments in classical mechanics.
One-term course offered either term
Prerequisites: AP score of 5 on the Physics B or Physics C - Mechanics exam, or transfer credit for PHYS 91 or PHYS 93. Only for students with above prerequisites.
Activity: Laboratory
0.5 Course Units
Notes: Course carries .5 course unit and student receives grade. Permit required. Only for students with above prerequisites.

PHYS 051 Physics Laboratory II
Experiments in electromagnetism and optics.
One-term course offered either term
Prerequisites: 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. Only for students with above prerequisites.
Activity: Laboratory
0.5 Course Units
Notes: Course carries .5 course unit and student receives grade. Permit required. Only for students with above prerequisites.

PHYS 080 Physics and Consciousness
We will explore the link between physics, physical models and quantitative thinking to areas of consciousness and brain research. This will include examples and phenomena in classical and quantum physics, the nature of physical measurements, observation, the role of the observer, the role of the human mind in interpreting reality and consciousness. Brain imaging studies enabled by physical phenomena may be used to support certain theories of how we process information. The course will be based on cutting edge physical phenomena and as quantitative as possible. We will explore related areas of psychology including the area of emotions and try to explore new links between them and the limits of quantitative approaches in these topics. We will explore decision making and links to quantum theories. For example, the making of a decision has been hypothesized to collapse "a thought wave into a particle". Much of human thinking is probabilistic in nature and we will link this to physics. We will explore topics of quantum entanglement, quantum computing, information, and free will. We will explore other work showing that quantum models were able to predict effects shown in national surveys. We will explore how the brain works, how this is linked to physics, physicists' ways of thinking, as well as psychology (and develop useful methods for rational living).
For BA Students: Natural Science and Math Sector
Activity: Lecture
1 Course Unit
**PHYS 101 General Physics: Mechanics, Heat and Sound**
An introduction to the classical laws of motion, including kinematics, forces in nature, Newton's laws of motion, conservation of energy and momentum, fluid statics and dynamics, oscillations, and waves. Suggested for students in a pre-health program. Credit is awarded for only one of the following courses: PHYS 008, 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.
For BA Students: Physical World Sector
Course offered summer, fall and spring terms
Prerequisites: Entrance credit in algebra and trigonometry.
Corequisite: PHYS 101 LAB
Activity: Lecture
1.5 Course Unit
Notes: Credit is awarded for only one of the following courses: PHYS 008, 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.

**PHYS 102 General Physics: Electromagnetism, Optics, and Modern Physics**
A continuation of PHYS 101 emphasizing an introduction to classical electricity and magnetism, light and optics, special relativity, the quantum theory of matter, and nuclear physics. Suggested for students in a pre-health program. Credit is awarded for only one of the following courses: PHYS 009, 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.
For BA Students: Physical World Sector
Course offered summer, fall and spring terms
Prerequisites: PHYS 101, 150, or 170, entrance credit in algebra and trigonometry.
Corequisite: PHYS 102 LAB
Activity: Lecture
1 Course Unit
Notes: Credit is awarded for only one of the following courses: PHYS 009, 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.

**PHYS 137 Community Physics Initiative**
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.
Course usually offered in fall term
Activity: Lecture
1 Course Unit

**PHYS 140 Principles of Physics I (without laboratory)**
The topics of this calculus-based course are: Classical laws of motions; interactions between particles; conservation laws and symmetry principles; particle and rigid body motion; gravitation, harmonic motion, and applications of mechanics to real-world problems. Engineering students only.
One-term course offered either term
Corequisite: MATH 104
Activity: Lecture
1 Course Unit
Notes: For Engineering students whose course of study does not require a physics laboratory course. Those who are enrolled in a dual degree program with the College must register for the lab-based version of this course, PHYS 150.

**PHYS 141 Principles of Physics II (without laboratory)**
The topics of this calculus-based course are electric and magnetic fields; Coulomb's, Gauss's, Ampere's, and Faraday's laws; DC and AC circuits; Maxwell's equations and electromagnetic radiation. Engineering students only.
Course offered summer, fall and spring terms
Prerequisite: PHYS 140
Corequisite: MATH 114
Activity: Lecture
1 Course Unit
Notes: For Engineering students whose course of study does not require a physics laboratory course. Those who are enrolled in a dual degree program with the College must register for the lab-based version of this course, PHYS 151.

**PHYS 150 Principles of Physics I: Mechanics and Wave Motion**
This calculus-based course is 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, and applications of mechanics to real-world problems. Credit is awarded for only one of the following courses: PHYS 008, 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.
For BA Students: Physical World Sector
One-term course offered either term
Prerequisites: Students in PHYS 150 should already have taken MATH 104 or the equivalent, or be taking it simultaneously with PHYS 150
Corequisite: PHYS 150 LAB
Activity: Lecture
1.5 Course Unit
Notes: Credit is awarded for only one of the following courses: PHYS 008, 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.
PHYS 151 Principles of Physics II: Electromagnetism and Radiation
The topics of this calculus-based course are electric and magnetic fields; Coulomb's, Gauss's, Ampere's, and Faraday's laws; DC and AC circuits; Maxwell's equations and electromagnetic radiation. Credit is awarded for only one of the following courses: PHYS 009, 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. For BA Students: Physical World Sector
Course offered summer, fall and spring terms
Prerequisites: PHYS 150; Students in PHYS 151 should already have taken MATH 114 or the equivalent, or be taking it simultaneously with PHYS 151
Corequisite: PHYS 151 LAB
Activity: Lecture
1.5 Course Unit
Notes: Credit is awarded for only one of the following courses. PHYS 009, 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.

PHYS 170 Honors Physics I: Mechanics and Wave Motion
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; non-inertial reference frames; oscillations. Credit is awarded for only one of the following courses: PHYS 008 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 Transfer Credit. For BA Students: Physical World Sector
Course usually offered in fall term
Prerequisite: MATH 104 or permission of instructor
Corequisites: MATH 114 or MATH 116, PHYS 170 lab
Activity: Seminar
1.5 Course Unit
Notes: Benjamin Franklin Seminar. Credit is awarded for only one of the following courses: PHYS 008 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 Transfer Credit.

PHYS 171 Honors Physics II: Electromagnetism and Radiation
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. Credit is awarded for only one of the following courses: PHYS 009, 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. For BA Students: Physical World Sector
Course usually offered in spring term
Prerequisites: Math 114 or Math 116 and Phys 150 or Phys 170, or permission of the instructor
Corequisites: MATH 240, MATH 260 or permission of instructor
Activity: Seminar
1.5 Course Unit
Notes: Benjamin Franklin Seminar. Credit is awarded for only one of the following courses: PHYS 009, 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.

PHYS 230 Principles of Physics III: Thermal Physics and Waves
Laws of thermodynamics, gas laws and heat engines. Waves on a string, electromagnetic waves including optical phenomena such as refraction, interference and diffraction. Introduction to special relativity including time dilation, length contraction, simultaneity, Lorentz transforms and relativistic energy and momentum. Students are encouraged but not required to take Math 240 concurrently or in advance.
Course usually offered in fall term
Prerequisites: PHYS 150/151 or PHYS 170/171 and MATH 104, MATH 114 or 116
Corequisite: MATH 240
Activity: Lecture
1 Course Unit

PHYS 240 Principles of Physics IV: Modern Physics (without laboratory)
An introduction to the experimental basis for and 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. Students are encouraged but not required to take Math 241 concurrently or in advance.
Course usually offered in spring term
Prerequisite: PHYS 150/151 or PHYS 170/171
Corequisite: MATH 240 (Note: MATH 240 will become a prerequisite in Spring 2019)
Activity: Lecture
1 Course Unit

PHYS 250 Principles of Physics IV: Modern Physics
An introduction to the experimental basis for and 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. Students are encouraged but not required to take Math 241 concurrently or in advance.
Course usually offered in spring term
Prerequisite: PHYS 150/151 or PHYS 170/171
Corequisites: MATH 240. (Note: MATH 240 will become a prerequisite in Spring 2019)
Activity: Lecture
1.5 Course Unit
Notes: PHYS 250 students take a two-hour lab

PHYS 280 Physical Models of Biological Systems
Classic case studies of successful reductionistic models of complex phenomena, emphasizing the key steps of making estimates, using them to figure out which physical variables and phenomena will be most relevant to a given system, finding analogies to purely physical systems whose behavior is already known, and embodying those in a mathematical model, which is often implemented in computer code. Topics may include bacterial genetics, genetic switches and oscillators; systems that sense or utilize light; superresolution and other newmicroscopy methods; and vision and other modes of sensory transduction.
Course usually offered in fall term
Prerequisites: PHYS 101 (or higher), MATH 104-MATH 114 or MATH 104-MATH 115 or MATH 116. Recommended: previous or concurrent PHYS 102; basic background in chemistry and biology.
Activity Lecture
1 Course Unit
PHYS 299 Independent Study
Special projects and independent study under the direction of faculty member.
One-term course offered either term
Activity: Independent Study
1 Course Unit
Notes: Repetitive credit

PHYS 314 Ocean-Atmosphere Dynamics and Implications for Future Climate Change
This course covers the fundamentals of atmosphere and ocean dynamics, and aims to put these in the context of climate change in the 21st century. Large-scale atmospheric and oceanic circulation, the global energy balance, and the global energy balance, and the global hydrological cycle. We will introduce concepts of fluid dynamics and we will apply these to the vertical and horizontal motions in the atmosphere and ocean. Concepts covered include: hydrostatic law, buoyancy and convection, basic equations of fluid motions, Hadley and Ferrel cells in the atmosphere, thermohaline circulation, Sverdrup ocean flow, modes of climate variability (El-Nino, North Atlantic Oscillation, Southern Annular Mode). The course will incorporate student led discussions based on readings of the 2007 Intergovernmental Panel on Climate Change (IPCC) report and recent literature on climate change. Aimed at undergraduate or graduate students who have no prior knowledge of meteorology or oceanography or training in fluid mechanics. Previous background in calculus and/or introductory physics is helpful. This is a general course which spans many subdisciplines (fluid mechanics, atmospheric science, oceanography, hydrology).
Taught by: Marinov
Prerequisites: MATH 114 or permission of the instructor.
Activity: Lecture
1 Course Unit

PHYS 351 Analytical Mechanics
An intermediate course in the statics and dynamics of particles and rigid bodies. Lagrangian dynamics, central forces, non-inertial reference frames, and rigid bodies.
Course usually offered in spring term
Prerequisites: PHYS 150/151 or PHYS 170/171, MATH 104/114, and MATH 240, or permission of instructor.
Activity: Lecture
1 Course Unit

PHYS 360 Statistics, Data Mining, and Machine Learning
This is a practical course on computing, numerical methods, statistics, and data analysis techniques with particular emphasis on data mining and machine learning applied to large datasets. Topics include basic numerical methods and algorithms, probability theory, classical and Bayesian statistical inference, model fitting, Monte Carlo methods, and classification. We will be using Python for the exercises. Prior experience in programming (in any language) is required.
Prerequisites: MATH240, CIS110 or prior experience in programming
Activity: Lecture
1 Course Unit

PHYS 361 Electromagnetism I: Electricity and Potential Theory
First term course in intermediate electromagnetism. Topics include electrostatics, static potential theory, multipole expansions, Laplace equation, image solutions, fields in polarized matter.
Course usually offered in fall term
Prerequisites: PHYS 151 or 171, and MATH 241
Activity: Lecture
1 Course Unit

PHYS 362 Electromagnetism II: Magnetism, Maxwell's Equations, and Electromagnetic Waves
Second term course in intermediate electromagnetism. Topics include magnetostatics and fields, magnetized media, Maxwell's equations, Poynting and stress theorems, free field solutions to Maxwell's equations, and radiation from separable and nonseparable time dependent charge and current distributions.
Course usually offered in spring term
Prerequisite: PHYS 361
Activity: Lecture
1 Course Unit

PHYS 364 Laboratory Electronics
A laboratory-intensive survey of analog and digital electronics, intended to teach students of physics or related fields enough electronics to be effective in experimental research and to be comfortable learning additional topics from reference textbooks. Analog topics include voltage dividers, impedance, filters, operational amplifier circuits, and transistor circuits. Digital topics may include logic gates, finite-state machines, programmable logic devices, digital-to-analog and analog-to-digital conversion, and microcomputer concepts. Recommended for students planning to do experimental work in physical science.
One-term course offered either term
Prerequisites: Familiarity with electricity and magnetism at the level of PHYS 102, 141, 151 or 171.
Activity: Lecture
1 Course Unit

PHYS 401 Thermodynamics and the Introduction to Statistical Mechanics and Kinetic Theory
Entropy, temperature, and introduction to ensemble theory, distribution functions, and phase transitions.
Course usually offered in fall term
Prerequisite: PHYS 240 or 250
Activity: Lecture
1 Course Unit

PHYS 411 Introduction to Quantum Mechanics I
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.
Course usually offered in fall term
Prerequisites: PHYS 150 or 170, 240 or 250, and MATH 240 or MATH 260
Activity: Lecture
1 Course Unit

PHYS 412 Introduction to Quantum Mechanics II
Perturbation theory, variational principle, application of the quantum theory to atomic, molecular, and nuclear systems, and their interaction with radiation.
Course usually offered in spring term
Prerequisite: PHYS 411
Activity: Lecture
1 Course Unit
PHYS 414 Laboratory in Modern Physics
In this course you will have the opportunity to do a variety of experiments, ranging from "classic experiments" such as measuring G with a torsion balance, determining the relativistic mass of the electron, and muon lifetime, to experiments studying atomic spectroscopy, NMR, Optical pumping, Mössbauer effect, nuclear energy levels, interaction of gamma rays with matter, single photon interference, and magnetic susceptibility. There are also experiments using a High-Tc superconducting tunnel junction and a PET scanner. You will learn basic statistics, become proficient in analysis using Python, acquire an understanding of systematic errors, and learn how to write a professional report. Many of the laboratories provide excellent opportunities to exercise, and expand upon, the knowledge you have gained in your physics courses.
Course usually offered in spring term
Prerequisite: PHYS 411
Activity: Lecture
1 Course Unit

PHYS 421 Modern Optics
Course not offered every year
Prerequisites: PHYS 240 or 250 and 362, or permission of instructor
Activity: Lecture
1 Course Unit

PHYS 433 Order of Magnitude Physics
This course focuses on the art of estimating physical quantities to within the nearest factor of ten. Problem solving techniques such as dimensional analysis and scaling relations will be covered and applied to a wide range of topics including fluid mechanics, waves and sound, atomic physics, material properties, astrophysics, everyday life, and more. The course is intended for advanced undergraduate students.
One-term course offered either term
Prerequisite: Prerequisites: PHYS 411 or permission from instructor
Activity: Lecture
1 Course Unit

PHYS 499 Senior Honor Thesis
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.
One-term course offered either term
Prerequisites: PHYS 412 and 414
Activity: Independent Study
1 Course Unit

PHYS 500 Mathematical Methods of Physics
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.
Course usually offered in fall term
Activity: Lecture
1 Course Unit

PHYS 501 Introduction to Research
Introduction to research in particle, nuclear, condensed matter and astrophysics. Selected current topics from journals.
One-term course offered either term
Activity: Lecture
0 Course Units
Notes: Taken by all first-year graduate students. This is a required seminar that does not carry credit or a grade.

PHYS 503 General Relativity
This is a graduate level, introductory course in general relativity. The basics of general relativity will be covered with a view to understanding the mathematical background, the construction of the theory, and applications to the solar system, black holes, gravitational waves and cosmology. The latter part of the course will cover some of the basic modern topics in modern cosmology, including the current cosmological model, the accelerating universe, and open questions driving current research.
One-term course offered either term
Activity: Lecture
1 Course Unit

PHYS 505 Introduction to Cosmology
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.
Course offered spring; odd-numbered years
Prerequisite: Graduate standing in physics or permission of instructor
Activity: Lecture
1 Course Unit

PHYS 516 Electromagnetic Phenomena
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).
Course usually offered in spring term
Activity: Lecture
1 Course Unit

PHYS 517 Particle Cosmology
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.
One-term course offered either term
Activity: Lecture
1 Course Unit
PHYS 518 Introduction to Condensed Matter Physics
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.
Course usually offered in spring term
Prerequisites: Undergraduate training in quantum mechanics and statistical thermodynamics
Activity: Lecture
1 Course Unit

PHYS 521 Advanced Laboratory
In this course you will have the opportunity to do a variety of experiments, ranging from "classic experiments" such as measuring G with a torsion balance, determining the relativistic mass of the electron, and muon lifetime, to experiments studying atomic spectroscopy, NMR, Optical pumping, Mossbauer effect, nuclear energy levels, interaction of gamma rays with matter, single photon interference, and magnetic susceptibility. There are also experiments using a High-Tc superconducting tunnel junction and a PET scanner. You will learn basic statistics, become proficient in analysis using Python, acquire an understanding of systematic errors, and learn how to write a professional report. Many of the laboratories provide excellent opportunities to exercise, and expand upon, the knowledge you have gained in your physics courses.
Course usually offered in spring term
Activity: Lecture
1 Course Unit

PHYS 522 Introduction to Elementary Particle Physics
An introduction to elementary particles (photons, leptons, hadrons, quarks), their interactions, and the unification of the fundamental forces.
Course not offered every year
Prerequisites: Permission of instructor required.
Activity: Lecture
1 Course Unit

PHYS 526 Astrophysical Radiation
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.
Course offered fall; even-numbered years
Activity: Lecture
1 Course Unit

PHYS 528 Introduction to Liquid Crystals
Overview of liquid crystalline phases, their elasticity, topology, and dynamics.
One-term course offered either term
Activity: Lecture
1 Course Unit

PHYS 529 Modern Optics
Course offered spring; even-numbered years
Activity: Lecture
1 Course Unit

PHYS 530 Modern Optical Physics and Spectroscopy
Introduction to contemporary optics. Topics include propagation and guiding of light waves, interaction of electromagnetic radiation with matter, lasers, non-linear optics, coherent transient phenomena, photon correlation spectroscopies and photon diffusion.
Course not offered every year
Prerequisites: Working knowledge of electricity and magnetism and quantum mechanics. For example, at least at the level of Physics 362, PHYS 411.
Activity: Lecture
1 Course Unit
Notes: 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.

PHYS 531 Quantum Mechanics I
Graduate-level introduction to quantum theory. Topics covered include the postulates of quantum mechanics, unitary operators, time evolution and Schrodinger's equation, theory of angular momentum, density matrices, and Bell's inequalities. Other topics may include semi-classical (WKB) approximation, bound states techniques, periodic potentials and resonance phenomena.
Course usually offered in fall term
Prerequisites: A minimum of one semester of quantum mechanics at the advanced undergraduate level.
Activity: Lecture
1 Course Unit

PHYS 532 Quantum Mechanics II
Continuation of PHYS 531. Topics covered include the path integral formulation, symmetries in quantum mechanics, scattering theory, and decoherence. Other topics may include time independent and time dependent perturbation theory, and atomic and molecular systems.
Course usually offered in spring term
Prerequisite: PHYS 531
Activity: Lecture
1 Course Unit

PHYS 533 Topics in Cosmology
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 accessible 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.
Course not offered every year
Activity: Lecture
1 Course Unit
**PHYS 535 Topics in Theory of Living Systems**  
The goal of this course is to discuss broad conceptual theories that address complex phenomena of living systems. Example questions include: what is the molecular architecture of information processing in cells and developing organisms? What is the functional architecture of cooperative organization from molecules in a cell to whole organism social interactions? How is complex multi-factorial information represented in organisms? The course will meet once a week and students will research relevant papers, lead discussions, and generate synopsis of group discussions. At the end of the semester, faculty and students are expected to co-author a review report of the discussed topics.  
Taught by: Kim, Goulian, Akcay, Balasubramanian, Raj, Mossel  
Course not offered every year  
Prerequisite: Permission of instructor  
Activity: Seminar  
0.5 Course Units

**PHYS 561 Electromagnetism I**  
First term course in intermediate electromagnetism. Topics include electrostatics, static potential theory, multipole expansions, Laplace equation, image solutions, fields in polarized matter.  
Course usually offered in fall term  
Activity: Lecture  
1 Course Unit

**PHYS 562 Electromagnetism II: Magnetism, Maxwell's Equations, and Electromagnetic Waves**  
Second term course in intermediate electromagnetism. Topics include magnetostatic forces and fields, magnetized media, Maxwell's equations, Poynting and stress theorems, free field solutions to Maxwell's equations, and radiation from separable and nonseparable time dependent charge and current distributions.  
Course usually offered in spring term  
Activity: Lecture  
1 Course Unit

**PHYS 564 Laboratory Electronics**  
A laboratory-intensive survey of analog and digital electronics, intended to teach students of physics or related fields enough electronics to be comfortable learning additional topics on their own from a reference such as Horowitz and Hill. Specific topics will vary from year to year from the selection of topics listed below. Analog topics may include voltage dividers, impedance, filters, operational amplifier circuits, and transistor circuits. Digital topics may include logic gates, finite-state machines, programmable logic devices, digital-to-analog and analog-to-digital conversion, and microcomputer concepts. Recommended for students planning to do experimental work in physical science.  
One-term course offered either term  
Activity: Lecture  
1 Course Unit

**PHYS 580 Biological Physics**  
The course will explore the basic physical principles behind the structure and function of life across many length and time scales (molecule, cell, organism, population). Emphasis will be given on overarching physical themes such as entropy and biological noise, and how they affect the organization of living matter and its emergent properties. Topics may include biopolymers and single molecule biophysics, molecular motors, gene and transcription networks, pattern formation in biological systems, phyllotaxis, neural computing and evolution.  
Course not offered every year  
Prerequisites: MATH 240 and MATH 241 (or equivalent preparation), PHYS 401 or familiarity with statistical mechanics and thermodynamics.  
Activity: Lecture  
1 Course Unit  
Notes: Recommended: Basic background in biology.

**PHYS 581 Thermodynamics**  
Course usually offered in fall term  
Activity: Lecture  
1 Course Unit

**PHYS 582 Medical Radiation Engineering**  
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.  
Course usually offered in fall term  
Activity: Lecture  
1 Course Unit

**PHYS 585 Theoretical and Computational Neuroscience**  
This course will develop theoretical and computational approaches to structural and functional organization in the brain. The course will cover: (i) the basic biophysics of neural responses, (ii) neural coding and decoding with an emphasis on sensory systems, (iii) approaches to the study of networks of neurons, (iv) models of adaptation, learning and memory, (v) models of decision making, and (vi) ideas that address why the brain is organized the way that it is. The course will be appropriate for advanced undergraduates and beginning graduate students. A knowledge of multi-variable calculus, linear algebra and differential equations is required (except by permission of the instructor). Prior exposure to neuroscience and/or Matlab programming will be helpful.  
Course usually offered in spring term  
Also Offered As: BE 530, NGG 594  
Activity: Lecture  
1 Course Unit

**PHYS 601 Introduction to Field Theory**  
Elementary relativistic quantum field theory of scalar, fermion, and Abelian gauge fields. Feynman Diagrams.  
Course usually offered in fall term  
Activity: Lecture  
1 Course Unit

**PHYS 611 Statistical Mechanics**  
Course usually offered in fall term  
Prerequisites: PHYS 401, 531, or equivalent  
Activity: Lecture  
1 Course Unit
PHYS 612 Advanced Statistical Mechanics
In depth study of classical and quantum lattice spin models, perturbation
techniques, and the renormalization group.
Course not offered every year
Prerequisite: PHYS 611 or equivalent
Activity: Lecture
1 Course Unit

PHYS 622 Introduction to Elementary Particle Physics
Introduction to the phenomenology of elementary particles, strong and
weak interactions, symmetries.
Course not offered every year
Prerequisite: PHYS 601
Activity: Lecture
1 Course Unit

PHYS 632 Relativistic Quantum Field Theory
Advanced topics in field theory, including renormalization theory.
Course not offered every year
Prerequisite: PHYS 601
Activity: Lecture
1 Course Unit

PHYS 633 Relativistic Quantum Field Theory
A continuation of PHYS 632, dealing with non-Abelian gauge theories.
Course not offered every year
Prerequisite: PHYS 632
Activity: Lecture
1 Course Unit

PHYS 661 Solid State Theory I
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.
Course not offered every year
Activity: Lecture
1 Course Unit

PHYS 662 Solid State Theory II
A continuation of PHYS 661.
Course not offered every year
Activity: Lecture
1 Course Unit

PHYS 696 Advanced Topics in Theoretical Physics
Course not offered every year
Activity: Lecture
1 Course Unit

PHYS 990 Masters Thesis
One-term course offered either term
Activity: Masters Thesis
1 Course Unit

PHYS 995 Dissertation
One-term course offered either term
Activity: Dissertation
1 Course Unit

PHYS 999 Independent Study
One-term course offered either term
Activity: Independent Study
1 Course Unit