# PHYSICS (PHYS)

**Courses primarily for undergraduates:**

**PHYS 0500: Intro Physics Prep**
Credits: 0. Contact Hours: Lecture 3.
An in#depth active learning experience designed to impart the fundamental concepts and principles of physics, with an emphasis on applied mathematical techniques and logical thinking. For students intending to enroll in classical physics (PHYS 2310/2320) who have not taken high school physics, who have not had a high school college preparatory physics course, or who need a review of physics problem solving and physics concepts. 1 year high school algebra recommended. (Typically Offered: Fall, Spring)

**PHYS 1010: Physics for the Nonscientist**
Credits: 3. Contact Hours: Lecture 3.
Survey of the principal areas of both classical and modern physics. Emphasis on the nature of the physical universe and the application of physical principles to life in the modern world. (Typically Offered: Fall, Spring, Summer)

**PHYS 1020L: Physical Sciences for Elementary Education**
(Cross-listed with CHEM 1020L).
Credits: 3. Contact Hours: Lecture 1, Laboratory 4.
*Prereq: Credit or concurrent enrollment in* MATH 1950 *OR Permission of Instructor*
Physical science principles for future elementary teachers. Emphasis on experiments that address current elementary science education standards and that are appropriate for their future students to do, such as measurements of mass, length, time, light from atoms, charge and current, motion due to forces, energy and work, heat, waves, optics, building bridges and making musical instruments, studying states of matter and chemical reactions. (Typically Offered: Fall, Spring)

**PHYS 1150: Physics for the Life Sciences**
Credits: 4. Contact Hours: Lecture 3, Discussion 1.
Emphasis on basic physics principles applied to biological problems. Topics include mechanics, fluids, thermodynamics, heat, light, sound, electricity and magnetism. A coordinated laboratory, PHYS 1150 laboratory is available. 1.5 yr. HS algebra, 1 yr. HS geometry, 1 semester HS trigonometry recommended. (Typically Offered: Fall, Spring)

**PHYS 1150L: Laboratory in Physics for the Life Sciences**
Credits: 1. Contact Hours: Laboratory 2.
*Prereq: Credit or enrollment in* PHYS 1150
Experiments related to the elementary topics of physics for the life sciences. Mechanics, fluids, thermodynamics, heat, light, sound, electricity and magnetism. (Typically Offered: Fall, Spring)

**PHYS 1310: General Physics I**
Credits: 4. Contact Hours: Lecture 3, Discussion 1.
General background in physical concepts, principles, and methods for those who do not plan advanced study in physics or engineering. Mechanics, fluids, heat and thermodynamics, vibrations, waves, sound. 1.5 yr. HS algebra, 1 yr. HS geometry, 1 semester HS trigonometry recommended. (Typically Offered: Fall, Spring, Summer)

**PHYS 1310L: General Physics I Laboratory**
Credits: 1. Contact Hours: Laboratory 2.
Laboratory experiments in elementary kinematics, work and energy, conservation laws, rotational motion, waves and fluids. 1.5 yr. HS algebra, 1 yr. HS geometry, 1 semester HS trigonometry recommended. (Typically Offered: Fall, Spring, Summer)

**PHYS 1320: General Physics II**
Credits: 4. Contact Hours: Lecture 3, Discussion 1.
*Prereq:* PHYS 1310 *or* PHYS 2310
General background in physical concepts, principles, and methods for those who do not plan advanced study in physics or engineering. Electricity and magnetism, ray and wave optics, topics in modern physics. (Typically Offered: Fall, Spring, Summer)

**PHYS 1320L: General Physics II Laboratory**
Credits: 1. Contact Hours: Laboratory 2.
*Prereq:* PHYS 1320
Laboratory experiments in Electricity and Magnetism, Wave and Optics. (Typically Offered: Fall, Spring, Summer)

**PHYS 1320Q: Ap - General Physics II Laboratory**
Credits: 0-99. Contact Hours: Laboratory 2.

**PHYS 1990: Introductory Seminar**
Credits: 1.
Gain experience in key skills that physicists/astronomers use routinely, but are rarely explicitly taught in formal courses. Participate in faculty-led discussions on frontier areas and careers. Offered on a satisfactory-fail basis only. (Typically Offered: Fall)

**PHYS 2310: Introduction to Classical Physics I**
Credits: 4. Contact Hours: Discussion 1, Lecture 3.
*Prereq:* MATH 1650*; credit or concurrent enrollment in* MATH 1660
For engineering and science majors. 3 hours of lecture each week plus 3 recitations every two weeks. Elementary mechanics including kinematics and dynamics of particles, work and energy, linear and angular momentum, conservation laws, rotational motion, oscillations, gravitation. Heat, thermodynamics, kinetic theory of gases; waves and sound. Proficiency in algebra, trigonometry, vector manipulation required. (Typically Offered: Fall, Spring)

**PHYS 2310H: Introduction to Classical Physics I: Honors**
Credits: 4. Contact Hours: Lecture 3, Discussion 1.
*Prereq:* MATH 1650*; credit or concurrent enrollment in* MATH 1660
For engineering and science majors. 3 hours of lecture each week plus 3 recitations every two weeks. Elementary mechanics including kinematics and dynamics of particles, work and energy, linear and angular momentum, conservation laws, rotational motion, oscillations, gravitation. Heat, thermodynamics, kinetic theory of gases; waves and sound. Proficiency in algebra, trigonometry, vector manipulation required. (Typically Offered: Fall, Spring, Summer)

**PHYS 2310L: Introduction to Classical Physics I Laboratory**
Credits: 1. Contact Hours: Laboratory 2.
*Prereq:* MATH 1650 *AND (credit or enrollment in* MATH 1660*) AND (credit or concurrent enrollment in* PHYS 2310 *or* PHYS 2410*)*
Laboratory experiments in elementary kinematics, work and energy, conservation laws, and rotational motion. Proficiency in algebra, trigonometry, vector manipulation required. (Typically Offered: Fall, Spring, Summer)

**PHYS 2310Q: Ap - Introduction to Classical Physics I Laboratory**
Credits: 0-99. Contact Hours: Laboratory 2.

**PHYS 2320: Introduction to Classical Physics II**
Credits: 4. Contact Hours: Discussion 1, Lecture 3.
*Prereq:* MATH 1660*;* PHYS 2310 *or* PHYS 2410
3 hours of lecture each week plus 1 recitation each week. Fluid dynamics. Electric forces and fields. Electrical currents; DC circuits. Magnetic forces and fields; LR, LC, LCR circuits; Maxwell's equations; wave optics. (Typically Offered: Fall, Spring, Summer)

**PHYS 2320H: Introduction to Classical Physics II: Honors**
Credits: 4. Contact Hours: Lecture 3, Discussion 1.
*Prereq:* MATH 1660*;* PHYS 2310 *or* PHYS 2410
3 hours of lecture each week plus 1 recitation each week. Fluid dynamics. Electric forces and fields. Electrical currents; DC circuits; Magnetic forces and fields; LR, LC, LCR circuits; Maxwell's equations; wave optics. (Typically Offered: Fall, Spring)

**PHYS 2320L: Introduction to Classical Physics II Laboratory**
Credits: 1. Contact Hours: Laboratory 2.
*Prereq:* MATH 1660 *AND (Credit or concurrent enrollment in* PHYS 2320 *or* PHYS 2420*)*
Laboratory experiments in fluid dynamics, electric forces and fields, electrical currents, DC circuits, magnetic forces and fields, and wave optics. (Typically Offered: Fall, Spring, Summer)

**PHYS 2320Q: Ap - Introduction to Classical Physics II Laboratory**
Credits: 0-99. Contact Hours: Laboratory 2.

**PHYS 2410: Principles and Symmetries in Classical Physics I**
Credits: 5. Contact Hours: Lecture 3, Discussion 1.5, Laboratory 1.
*Prereq:* MATH 1650*; credit or concurrent enrollment in* MATH 1660
Covers all of mechanics; kinematics and dynamics of particles, work and energy, linear and angular momentum, conservation laws, rotational motion, oscillations, gravitation, and extremum principles. Topics in kinetic theory, thermodynamics, waves and sound. Proficiency in algebra, trigonometry, vector manipulation required. (Typically Offered: Fall)

**PHYS 2410H: Principles and Symmetries in Classical Physics I: Honors**
Credits: 5. Contact Hours: Lecture 3, Discussion 1.5, Laboratory 1.
*Prereq:* MATH 1650*; credit or concurrent enrollment in* MATH 1660
Covers all of mechanics; kinematics and dynamics of particles, work and energy, linear and angular momentum, conservation laws, rotational motion, oscillations, gravitation, and extremum principles. Topics in kinetic theory, thermodynamics, waves and sound. Proficiency in algebra, trigonometry, vector manipulation required. (Typically Offered: Fall)

**PHYS 2420: Principles and Symmetries in Classical Physics II**
Credits: 5. Contact Hours: Lecture 3, Discussion 1, Laboratory 2.
*Prereq:* PHYS 2310 *or* PHYS 2410*; credit or concurrent enrollment in* MATH 1660
Fluid dynamics, electrostatics, potentials and fields, currents, fields of moving charges, the magnetic field, electromagnetic induction, DC and AC circuits, Maxwell's equations and electromagnetic waves, electric and magnetic fields in matter. Topics in optics and special relativity. (Typically Offered: Spring)

**PHYS 2420H: Principles and Symmetries in Classical Physics II: Honors**
Credits: 5. Contact Hours: Lecture 3, Discussion 1, Laboratory 2.
*Prereq:* PHYS 2310 *or* PHYS 2410*; credit or concurrent enrollment in* MATH 1660
Fluid dynamics, electrostatics, potentials and fields, currents, fields of moving charges, the magnetic field, electromagnetic induction, DC and AC circuits, Maxwell's equations and electromagnetic waves, electric and magnetic fields in matter. Topics in optics and special relativity. (Typically Offered: Spring)

**PHYS 2900: Independent Study**
Credits: 1-4. Repeatable.
*Prereq: Instructor Permission for Course*
(Typically Offered: Fall, Spring, Summer)

**PHYS 2990: Intermediate Seminar**
Credits: 1-2. Contact Hours: Lecture 2.
Conduct research or an independent study on topics in physics and astronomy. Learn science communication skills that physicists and astronomers use routinely. Offered on a satisfactory-fail basis only. (Typically Offered: Spring)

**PHYS 3020: The Challenge of Contemporary Physics**
Credits: 3. Contact Hours: Lecture 3.
*Prereq: Sophomore classification*
A largely nonmathematical but intellectually challenging exploration of physics, which assumes no previous work in the field. Selected material from classical and modern physics establishes the conceptual framework for the study of major areas of contemporary physics, culminating in the discussion of topics at the frontier of present knowledge. Topics vary yearly and may include quarks, lasers, superconductivity, fission and fusion, solid state devices, gravitational waves, string theory, facilities, left handed materials, and quantum computing. (Typically Offered: Spring)

**PHYS 3040: Thermal Physics**
Credits: 3. Contact Hours: Lecture 3.
*Prereq: (*MATH 2660 *or* MATH 2670*); ([*PHYS 2320*;* PHYS 2320L*] or [*PHYS 2420*])*
Concepts of temperature, entropy, and other characteristic thermodynamic functions, with application to macroscopic properties of matter. The laws of thermodynamics. Introduction to statistical mechanics, including quantum statistics. Application to black body radiation, crystalline vibrations, magnetic ions in solids, electronic heat capacity of metals. Phase transformations and chemical reactions. (Typically Offered: Spring)

**PHYS 3060: Physics of Wave Motion**
Credits: 3. Contact Hours: Lecture 3.
*Prereq: Credit or concurrent enrollment in (*MATH 2660 *or* MATH 2670*); ([*PHYS 2320*;* PHYS 2320L*] or [*PHYS 2420 *or* PHYS 2420H*])*
Oscillating systems including damped and forced oscillations; fluids, geometric optics, water waves, the wave equation, Fourier and Laplace transforms, non-uniform media, cylindrical and spherical waves, polarization, interference and diffraction, transmission lines, non-linear waves. (Typically Offered: Spring)

**PHYS 3100: Electronic Instrumentation for Experimental Physics**
Credits: 4. Contact Hours: Lecture 2, Laboratory 4.
*Prereq:* MATH 1660*; ([*PHYS 2320*;* PHYS 2320L*] or [*PHYS 2420*])*
Common electrical instruments; power supplies; transducers; passive and active devices, analog integrated circuits, including filters and amplifiers; digital integrated circuits; signal transmission and enhancement. (Typically Offered: Fall)

**PHYS 3110: Intermediate Laboratory**
Credits: 1-2. Contact Hours: Laboratory 2.
Repeatable.
*Prereq:* PHYS 3220
Experiments in classical and modern physics performed independently by each student. (Typically Offered: Spring)

**PHYS 3110T: Intermediate Laboratory for Secondary Physics Teachers**
Credits: 3. Contact Hours: Laboratory 6.
Repeatable.
*Prereq: (*PHYS 1320*;* PHYS 1320L*) or (*PHYS 2320 *or* PHYS 2320H*;* PHYS 2320L*) or* PHYS 2420
Experiments in classical and modern physics performed independently by each student. For students preparing for a career in high school teaching. (Typically Offered: Spring)

**PHYS 3210: Introduction to Modern Physics I**
Credits: 3. Contact Hours: Lecture 3.
*Prereq: Credit or concurrent enrollment in (*MATH 2660 *or* MATH 2670*); ([*PHYS 2320*;* PHYS 2320L*] or [*PHYS 2420 *or* PHYS 2420H*])*
Quantum nature of matter: photons, de Broglie's postulate: wave-like properties of matter; Bohr's model of hydrogen atom; Schrodinger equations in one dimension: energy quantization; detailed solutions for potential steps, barriers and wells; one-electron atoms, spin and magnetic interactions; ground states, optical and x-ray excitations of multi-electron atoms. (Typically Offered: Fall)

**PHYS 3210L: Introductory Laboratory in Modern Physics I**
Credits: 1. Contact Hours: Laboratory 2.
*Prereq: Credit or enrollment in* PHYS 3210
Experiments related to the foundations of modern physics. The dual wave and particle character of electrons and photons, statistics, interferometry and x-ray spectroscopy. (Typically Offered: Fall)

**PHYS 3220: Introduction to Modern Physics II**
Credits: 3. Contact Hours: Lecture 3.
*Prereq:* PHYS 3210
Quantum statistics; lasers; physics of molecules. Properties of solids, including electron band structure, superconductivity and magnetism. Nuclear physics, including nuclear sizes and masses, stability, decay modes, reactions, fission and fusion. Elementary particles, including strangeness, charm, and quarks. Fundamental forces of nature. (Typically Offered: Spring)

**PHYS 3220L: Introductory Laboratory in Modern Physics II**
Credits: 1. Contact Hours: Laboratory 2.
*Prereq: Credit or enrollment in* PHYS 3220
Experiments related to the foundations of modern physics. Radioactive decay, elementary particles, Hall effect, quantization, spectroscopy, statistics and instrumentation. (Typically Offered: Spring)

**PHYS 3610: Classical Mechanics**
Credits: 3. Contact Hours: Lecture 3.
Newtonian mechanics including forced oscillations, central forces and orbital motion, collisions, moving frames of reference, Lagrange's equations. (Typically Offered: Spring)

**PHYS 3620: Intermediate Mechanics**
Credits: 3. Contact Hours: Lecture 3.
*Prereq:* PHYS 3610
Rigid body motion; small oscillations, normal modes. Special relativity including length contraction, time dilation, simultaneity, Lorentz transformation, 4-vector covariant formalism, relativistic mechanics. (Typically Offered: Fall)

**PHYS 3640: Electricity and Magnetism I**
Credits: 3. Contact Hours: Lecture 3.
*Prereq: (*MATH 2660 *or* MATH 2670*); ([*PHYS 2320*;* PHYS 2320L*] or [*PHYS 2420*])*
Static electric and magnetic fields, potential theory; electromagnetism, Maxwell's equations. (Typically Offered: Fall)

**PHYS 3650: Electricity and Magnetism II**
Credits: 3. Contact Hours: Lecture 3.
*Prereq:* PHYS 3640 *and* MATH 3850
Relativistic electromagnetic theory; radiation and propagation of electromagnetic waves; interaction with matter. (Typically Offered: Spring)

**PHYS 3990: Seminar on Secondary School Physics**
Credits: 1-2. Contact Hours: Lecture 2.
Repeatable, maximum of 2 credits.
*Prereq: Instructor Permission for Course*
Review of materials and curricula for secondary school physics presented and discussed by members of the class. Required for approval to teach physics in secondary schools. (Typically Offered: Spring)

**PHYS 4210: Ultrafast Laser Science and Spectroscopy**
(Dual-listed with PHYS 5210).
Credits: 3. Contact Hours: Lecture 3.
*Prereq: (PHYS 3210; PHYS 3650) or Permission of Instructor*
Introduction to ultrafast lasers, nonlinear optics, and their applications. Topics selected from: basic optics, atom-photon interactions, electrodynamics of condensed matter, laser physics, ultrafast and nonlinear optics, ultrashort pulse generation, broadband pulse generation, time-resolved spectroscopy and instrumentation. (Typically Offered: Fall)

**PHYS 4220: Foundations of Quantum Computing**
(Dual-listed with PHYS 5220).
Credits: 3. Contact Hours: Lecture 3.
*Prereq: (*MATH 2070 *or* MATH 3170*) or Permission of Instructor*
Overview of quantum computation and quantum information processing from a physics perspective. Introduction to classical computation; primer on quantum mechanics; quantum circuits and quantum algorithms; physical realizations; applications and near-term quantum algorithms. (Typically Offered: Spring)

**PHYS 4320: Molecular and Cell Biophysics**
(Dual-listed with PHYS 5320).
Credits: 3. Contact Hours: Lecture 3.
*Prereq:* CHEM 3250 *or* PHYS 3040
Quantitative description of biological systems using basic physical laws, including a brief discussion of a variety of biophysical techniques. Topics include: thermodynamics, chemical equilibrium, gene expression, structure and physical properties of nucleic acids and proteins, folding of nucleic acids and proteins, chemical kinetics, catalysis, allosteric enzymes, cell membrane structure and physical properties, and machines in cell membranes. (Typically Offered: Spring)

**PHYS 4500: Undergraduate Research**
Credits: 1-6. Repeatable.
*Prereq: Instructor Permission for Course*
Theoretical research under supervision of physics faculty. (Typically Offered: Fall, Spring, Summer)

**PHYS 4500L: Undergraduate Research**
Credits: 1-6. Repeatable.
*Prereq: PHYS 3220L; Permission of Instructor*
Laboratory project under supervision of physics faculty. (Typically Offered: Fall, Spring, Summer)

**PHYS 4700L: Applied Physics Laboratory**
Credits: 2-5. Contact Hours: Laboratory 5.
Repeatable.
*Prereq:* PHYS 3220*; Permission of Instructor*
Studies in modern experimental techniques via experimentation and simulation in various areas of applied physics, e.g. superconductivity, optical spectroscopy, nuclear magnetic resonance, electron spin resonance, x-ray diffraction, and computation of electronic and structural properties of matter. (Typically Offered: Fall, Spring, Summer)

**PHYS 4800: Quantum Mechanics I**
Credits: 3. Contact Hours: Lecture 3.
*Prereq:* MATH 3850*,* PHYS 3210
First semester of a full-year course. A systematic development of the formalism and applications of quantum mechanics. Solutions to the time independent Schrodinger equation for various one-dimensional potentials including the harmonic oscillator; operator methods; Heisenberg picture; angular momentum; the hydrogen atom; spin; symmetry properties. (Typically Offered: Fall)

**PHYS 4810: Quantum Mechanics II**
Credits: 3. Contact Hours: Lecture 3.
Continuation of 4800. Addition of angular momentum; charged particles in electromagnetic fields; time-independent perturbation theory; variational principles; WKB approximation; interaction picture; time-dependent perturbation theory; adiabatic approximation; scattering; selected topics in radiation theory; quantum paradoxes. (Typically Offered: Fall, Spring, Summer)

**PHYS 4900: Independent Study**
Credits: 1-4. Repeatable, maximum of 9 credits.
*Prereq: 6 credits in PHYS; Permission of Instructor*
Graduation Restriction: No more than 9 credits of PHYS 4900 may be counted toward graduation. (Typically Offered: Fall, Spring, Summer)

**PHYS 4900H: Independent Study: Honors**
Credits: 1-4. Repeatable, maximum of 9 credits.
*Prereq: 6 credits in PHYS; Permission of Instructor*
Graduation Restriction: No more than 9 credits of PHYS 4900 may be counted toward graduation. (Typically Offered: Fall, Spring, Summer)

**PHYS 4960: Modern Optics**
(Cross-listed with EE 4960).
Credits: 3. Contact Hours: Lecture 3.
*Prereq: Credit or enrollment in* PHYS 3220*,* PHYS 3650*, and* PHYS 4800
Review of wave and electromagnetic theory; topics selected from: reflection/refraction, interference, geometrical optics, Fourier analysis, dispersion, coherence, Fraunhofer and Fresnel diffraction, holography, quantum optics, nonlinear optics. (Typically Offered: Fall)

**Courses primarily for graduate students, open to qualified undergraduates:**

**PHYS 5010: Oral Communication of Physics Seminar**
Credits: 1. Contact Hours: Lecture 1.
Repeatable.
A practical introduction to communication methods in physics and astronomy classrooms and professional settings. For graduate physics majors only. Offered on a satisfactory-fail basis only. (Typically Offered: Fall, Spring, Summer)

**PHYS 5020: Introductory Research Seminar**
Credits: Required. Contact Hours: Lecture 1.
Discussion by research staff of their research areas, expected thesis research work, and opportunities in the field. For graduate physics majors only. Offered on a satisfactory-fail basis only. (Typically Offered: Fall)

**PHYS 5110: Condensed Matter Physics I**
Credits: 3. Contact Hours: Lecture 3.
First semester of a full-year course. Free electron model; crystal symmetry; band theory of solids; transport properties; Fermi surface; phonons; semiconductors; crystal surfaces; magnetism; superconductivity. (Typically Offered: Fall, Spring, Summer)

**PHYS 5120: Condensed Matter Physics II**
Credits: 3. Contact Hours: Lecture 3.
Continuation of 5110. Free electron model; crystal symmetry; band theory of solids; transport properties; Fermi surface; phonons; semiconductors; crystal surfaces; magnetism; superconductivity. (Typically Offered: Fall, Spring, Summer)

**PHYS 5220: Foundations of Quantum Computing**
(Dual-listed with PHYS 4220).
Credits: 3. Contact Hours: Lecture 3.
Overview of quantum computation and quantum information processing from a physics perspective. Introduction to a classical computation; primer on quantum mechanics; quantum circuits and quantum algorithms; physical realizations; applications and near-term quantum algorithms. (Typically Offered: Fall, Spring, Summer)

**PHYS 5260: Particle and Nuclear Physics**
Credits: 4. Contact Hours: Lecture 4.
Basic properties and structures of nuclei, hadrons, and elementary particles; weak and strong interactions; the Standard Model; accelerators and detectors; nuclear models; nuclear decay and stability; nuclear astrophysics; the Higgs mechanism; the CKM matrix; running coupling constants; relativistic heavy-ion collisions; selected topics beyond the standard model such as SUSY and grand unification. (Typically Offered: Fall, Spring, Summer)

**PHYS 5280: Mathematical Methods for the Physical Sciences**
Credits: 3. Contact Hours: Lecture 3.
Fast-paced coverage of mathematical techniques needed for advanced analysis in the physical sciences, particularly for quantum mechanics and electrodynamics. Linear vector spaces and operators. Linear differential equations for time-evolution and steady-state problems, Green's functions and propagators, Sturm-Liouville problems. Functions of a complex variable, calculus of residues, series expansions, integral transforms and applications. (Typically Offered: Fall)

**PHYS 5310: Statistical Mechanics**
Credits: 3. Contact Hours: Lecture 3.
Thermodynamic properties of systems of many particles obeying Boltzmann, Fermi-Dirac, and Bose-Einstein statistics; microcanonical, canonical, and grand canonical ensembles and their application to physical problems; density matrices; introduction to phase transitions; renormalization group theory; kinetic theory and fluctuations. (Typically Offered: Spring)

**PHYS 5320: Molecular and Cell Biophysics**
(Dual-listed with PHYS 4320).
Credits: 3. Contact Hours: Lecture 3.
Quantitative description of biological systems using basic physical laws, including a brief discussion of a variety of biophysical techniques. Topics include: thermodynamics, chemical equilibrium, gene expression, structure and physical properties of nucleic acids and proteins, folding of nucleic acids and proteins, chemical kinetics, catalysis, allosteric enzymes, cell membrane structure and physical properties, and machines in cell membranes. (Typically Offered: Spring)

**PHYS 5340: Symmetry and Group Theory in Physics**
Credits: 3. Contact Hours: Lecture 3.
Theory of groups and group representations; introduction to both point and continuous groups, and their applications in physics. (Typically Offered: Fall)

**PHYS 5350: Physics of Semiconductors**
(Cross-listed with EE 5350).
Credits: 4. Contact Hours: Lecture 3, Laboratory 3.
Basic elements of quantum theory, Fermi statistics, motion of electrons in periodic structures, crystal structure, energy bands, equilibrium carrier concentration and doping, excess carriers and recombination, carrier transport at low and high fields, space charge limited current, photo-conductivity in solids, phonons, optical properties, amorphous semiconductors, heterostructures, and surface effects. Laboratory experiments on optical properties, carrier lifetimes, mobility, defect density, doping density, photo-conductivity, diffusion length of carriers.

**PHYS 5360: Physics of Semiconductor Devices**
(Cross-listed with EE 5360).
Credits: 3. Contact Hours: Lecture 3.
*Prereq: EE 5350*
P-n junctions, band-bending theory, tunneling phenomena, Schottky barriers, heterojunctions, bipolar transistors, field-effect transistors, negative-resistance devices and optoelectronic devices.

**PHYS 5410: General Relativity**
Credits: 3. Contact Hours: Lecture 3.
Tensor analysis and differential geometry developed and used to formulate Einstein field equations. Schwarzschild and Kerr solutions. Other advanced topics may include gravitational radiation, particle production by gravitational fields, alternate gravitational theories, attempts at unified field theories, cosmology. (Typically Offered: Fall)

**PHYS 5510: Computational Physics**
Credits: 3. Contact Hours: Laboratory 2.
Use of computational methods to solve complex problems in physics and carry out data analysis. (Typically Offered: Spring)

**PHYS 5640: Advanced Classical Mechanics**
Credits: 3. Contact Hours: Lecture 3.
Variational principles, Lagrange's equations, Hamilton's canonical equations, canonical transformations, Hamilton-Jacobi theory, infinitesimal transformations, classical field theory, canonical perturbation theory, classical chaos. (Typically Offered: Spring)

**PHYS 5710: Electricity and Magnetism I**
Credits: 3. Contact Hours: Lecture 3.
Electrostatics, magnetostatics, boundary value problems, Maxwell's equations, wave phenomena in macroscopic media, wave guides. (Typically Offered: Fall)

**PHYS 5720: Electricity and Magnetism II**
Credits: 3. Contact Hours: Lecture 3.
Special theory of relativity, least action and motion of charged particles in electromagnetic fields, radiation, collisions between charged particles, multipole fields, radiation damping. (Typically Offered: Spring)

**PHYS 5900A: Nuclear Physics**
Credits: 1-30. Repeatable.
*Prereq: Instructor Permission for Course*
Topics of current interest. (Typically Offered: Fall, Spring, Summer)

**PHYS 5900B: Condensed Matter Physics**
Credits: 1-30. Repeatable.
*Prereq: Instructor Permission for Course*
Topics of current interest. (Typically Offered: Fall, Spring, Summer)

**PHYS 5900C: High Energy Physics**
Credits: 1-30. Repeatable.
*Prereq: Instructor Permission for Course*
Topics of current interest. (Typically Offered: Fall, Spring, Summer)

**PHYS 5900D: Physics**
Credits: 1-30. Repeatable.
*Prereq: Instructor Permission for Course*
Topics of current interest. (Typically Offered: Fall, Spring, Summer)

**PHYS 5900E: Applied Physics**
Credits: 1-30. Repeatable.
*Prereq: Instructor Permission for Course*
Topics of current interest. (Typically Offered: Fall, Spring, Summer)

**PHYS 5900F: Biophysics**
Credits: 1-30. Repeatable.
*Prereq: Instructor Permission for Course*
Topics of current interest. (Typically Offered: Fall, Spring, Summer)

**PHYS 5910: Quantum Physics I**
Credits: 4. Contact Hours: Lecture 4.
First semester of a full-year course. Postulates of quantum mechanics; time-dependent and time-independent Schrodinger equations for one-,two-, and three-dimensional systems; theory of angular momentum; Rayleigh-Schrodinger time-independent perturbation theory. (Typically Offered: Fall)

**PHYS 5920: Quantum Physics II**
Credits: 4. Contact Hours: Lecture 4.
Continuation of 5910. Variational theorem and WKB method; time-dependent perturbation theory and 2nd quantization of the EM field in Coulomb gauge; method of partial waves and Born approximation for scattering by central potentials; identical particles and symmetry; Dirac and Klein-Gordon equation for free particles; path integral formalism. (Typically Offered: Spring)

**PHYS 5990: Creative Component**
Credits: 1-30. Repeatable.
*Prereq: Instructor Permission for Course*
Individually directed study of research-level problems for students electing the nonthesis M.S. degree option. (Typically Offered: Fall, Spring, Summer)

**Courses for graduate students:**

**PHYS 6110: Quantum Theory of Condensed Matter**
Credits: 3. Contact Hours: Lecture 3.
Quantum theory of interacting many body systems: zero temperature field theory, Fermi systems, finite temperature field theory, superconductivity and superfluidity. Gauge theories and topological phases of matter: lattice gauge theory, quantum hall effect, and topological field theories. (Typically Offered: Spring)

**PHYS 6240: Advanced Nuclear Physics**
Credits: 3. Contact Hours: Lecture 3.
Microscopic few-body and many-body theory; theory of effective Hamiltonians; relativistic nuclear physics; nuclear effects in hadron-nucleus, lepton-nucleus, and nucleus-nucleus reactions. (Typically Offered: Fall, Spring, Summer)

**PHYS 6250: Physics of Strong Interactions**
Credits: 3. Contact Hours: Lecture 3.
Quark model; Quantum Chromodynamics IQCD); perturbation methods for QCD; effective field theories for pions and nucleons; finite temperature field theories; quark-gluon plasma; phase transitions in QCD. (Typically Offered: Fall, Spring, Summer)

**PHYS 6370: Elementary Particle Physics I**
Credits: 3. Contact Hours: Lecture 3.
First semester of a full year course. Properties of leptons, bosons, and quarks and their interactions; quantum chromodynamics, Glashow-Weinberg-Salam model, grand unification theories, supersymmetry; modern theoretical techniques and tests of the Standard Model. (Typically Offered: Spring)

**PHYS 6380: Elementary Particle Physics II**
Credits: 3. Contact Hours: Lecture 3.
Continuation of 6370. Properties of leptons, bosons, and quarks and their interactions; quantum chromodynamics, Glashow-Weinberg-Salam model, grand unification theories, supersymmetry, and superstring theory; modern theoretical techniques. (Typically Offered: Fall, Spring, Summer)

**PHYS 6460: Mathematical Modeling of Complex Physical Systems**
(Cross-listed with MATH 6460).
Credits: 3. Contact Hours: Lecture 3.
Modeling of the dynamics of complex systems on multiple scales: Classical and dissipative molecular dynamics, stochastic modeling and Monte-Carlo simulation; coarse grained nonlinear dynamics, interface propagation and spatial pattern formation. (Typically Offered: Spring)

**PHYS 6500A: Nuclear Physics**
Credits: 1. Contact Hours: Lecture 1.
Repeatable.
Topics of current interest. Offered on a satisfactory-fail basis only. (Typically Offered: Fall, Spring, Summer)

**PHYS 6500B: Condensed Matter Physics**
Credits: 1. Contact Hours: Lecture 1.
Repeatable.
Topics of current interest. Offered on a satisfactory-fail basis only. (Typically Offered: Fall, Spring, Summer)

**PHYS 6500C: High Energy Physics**
Credits: 1. Contact Hours: Lecture 1.
Repeatable.
Topics of current interest. Offered on a satisfactory-fail basis only. (Typically Offered: Fall, Spring, Summer)

**PHYS 6500D: Physics**
Credits: 1. Contact Hours: Lecture 1.
Repeatable.
Topics of current interest. Offered on a satisfactory-fail basis only. (Typically Offered: Fall, Spring, Summer)

**PHYS 6500E: Applied Physics**
Credits: 1. Contact Hours: Lecture 1.
Repeatable.
Topics of current interest. Offered on a satisfactory-fail basis only. (Typically Offered: Fall, Spring, Summer)

**PHYS 6500F: Biophysics**
Credits: 1. Contact Hours: Lecture 1.
Repeatable.
Topics of current interest. Offered on a satisfactory-fail basis only. (Typically Offered: Fall, Spring, Summer)

**PHYS 6600B: Condensed Matter Physics**
Credits: 1-3. Contact Hours: Lecture 3.
Repeatable.
Courses on advanced topics and recent developments. (Typically Offered: Fall, Spring, Summer)

**PHYS 6600C: High Energy Physics**
Credits: 1-3. Contact Hours: Lecture 3.
Repeatable.
Courses on advanced topics and recent developments. (Typically Offered: Fall, Spring, Summer)

**PHYS 6600D: Physics**
Credits: 1-3. Contact Hours: Lecture 3.
Repeatable.
Courses on advanced topics and recent developments. (Typically Offered: Fall, Spring, Summer)

**PHYS 6600E: Applied Physics**
Credits: 1-3. Contact Hours: Lecture 3.
Repeatable.
Courses on advanced topics and recent developments. (Typically Offered: Fall, Spring, Summer)

**PHYS 6600F: Biophysics**
Credits: 1-3. Contact Hours: Lecture 3.
Repeatable.
Courses on advanced topics and recent developments. (Typically Offered: Fall, Spring, Summer)

**PHYS 6810: Quantum Field Theory I**
Credits: 3. Contact Hours: Lecture 3.
Quantization of fields (canonical and path integral); Feynman rules; introduction to gauge theories; Quantum Electrodynamics; radiative corrections; renormalization and renormalization group. (Typically Offered: Fall)

**PHYS 6820: Quantum Field Theory II**
Credits: 3. Contact Hours: Lecture 3.
Continuation of 6810. Systematics of renormalization; renormalization group methods; symmetries; spontaneous symmetry breaking; non-abelian gauge theories; the Standard Model and beyond; special topics. (Typically Offered: Fall, Spring)

**PHYS 6990: Research**
Credits: 1-30. Repeatable.
*Prereq: Instructor Permission for Course*
Graduate research. (Typically Offered: Fall, Spring, Summer)