PHYSICS AND ASTRONOMY

Office: 135 Physics Research Building; 313-577-2721
Chairperson: Peter Hoffmann
https://clas.wayne.edu/physics/ (http://www.clas.wayne.edu/physics/)

Physics is the science that describes the behavior of the physical world. It is the most basic of all sciences and as such is responsible for the interpretation of fundamental physical processes which support many other scientific disciplines.

The degree programs of this department are designed to provide students with the broad-based knowledge and problem-solving skills that are needed in order to be productive physicists in an academic, government, or industrial environment. The programs can accommodate students with varying undergraduate backgrounds and are designed to provide maximum flexibility for individual students. At the doctoral level, specializations are offered in the areas of: elementary particle physics, nuclear physics, condensed matter physics, atomic physics, materials science, optics, biophysics, and quantum field theory.

Faculty members are committed to excellence in research and teaching, and work in an open and informal atmosphere which allows effective communication between students and advisors. The faculty hold national and international reputations in their areas of specialization. They organize and participate in conferences, publish extensively, and receive numerous outside grants, contracts and fellowships. In addition, they engage in many collaborations with scientists in both foreign and American universities and national laboratories. The department is housed in a modern physics building containing well-equipped research laboratories.

BONVICINI, GIOVANNI: Laurea in Fisica, University of Bologna; Professor

BOWEN, DAVID: Ph.D., University of Pennsylvania; B.A., Haverford College; Associate Professor

CACKETT, EDWARD M: Ph.D., University of St. Andrews; M.S., University of Durham; Associate Professor

CHU, XIANG-QIANG: Ph.D., Massachusetts Institute of Technology; M.S., B.S., Peking University; Assistant Professor

CINABRO, DAVID A.: Ph.D., University of Wisconsin-Madison; B.A., University of Chicago; Professor

GAVIN, SEAN: Ph.D., M.S., University of Illinois; B.S., State University of New York at Stony Brook; Professor

HARR, ROBERT F.: Ph.D., M.S., University of California, Berkeley; B.S., Carnegie-Mellon University; Professor

HOFFMANN, PETER M.: Ph.D., Johns Hopkins University; M.S., Southern Illinois University; B.S., Technische Universitat Clausthal; Professor and Chair

HUANG, JIAN: Ph.D., Michigan State University; M.S., University of South Carolina; B.S., Beijing University; Associate Professor

HUANG, ZHIFENG: Ph.D., B.S., Tsinghua University; Associate Professor

KARCHIN, PAUL E.: Ph.D., M.S., B.S., Cornell University; Professor

KELLY, CHRISTOPHER V.: Ph.D., M.S.E., University of Michigan; B.A., Oberlin College; Assistant Professor

KEYES, PAUL H.: Ph.D., University of Maryland; B.S. Rensselaer Polytechnic Institute; Professor Emeritus

LLOPE, WILLIAM J.: Ph.D., M.S., State University of New York at Stony Brook; B.A., University of Michigan; Associate Professor

MAJUMDER, ABHIJIT: Ph.D., McGill University; M.Sc., B.Sc., Indian Institute of Technology-Kharagpur; Associate Professor

MORGAN, CAROLINE G.: Ph.D., Princeton University; B.S., Swarthmore College; Professor

MUKHOPADHYAY, ASHIS: Ph.D., Kansas State University; M.Sc., B.Sc., University of Calcutta; Associate Professor

NADGORNY, BORIS E.: Ph.D., State University of New York at Stony Brook; B.S., Moscow Institute of Physics and Technology; Professor

NAIK, RATNA: Ph.D., West Virginia University; M.Sc., B.Sc., Mysore University; Professor

PADMANABHAN, KARUR R.: Ph.D., M.Sc., Poona University; Associate Professor

PAZ, GIL: Ph.D., Cornell University; M.S., B.A., Israel Institute of Technology; Assistant Professor

PETROV, ALEXEY A.: Ph.D., M.S., University of Massachusetts, Amherst; B.S., St. Petersburg Technical University; Professor

PRUNEAU, CLAUDE A.: Ph.D., M.Sc., B.Sc., Universite Laval; Professor

PUTSCHKE, JOERN: Ph.D., Technical University of Munich; Dipl, University of Marburg; Associate Professor

SAKAMOTO, TAKESHI: Ph.D., Kanazawa University; B.S., Nihon University; Associate Professor

SHAH, NAUSHEEN: Ph.D., University of Chicago; B.Sc., George Mason University; Assistant Professor

VOLOSHIN, SERGEI A.: Ph.D., Dipl, Moscow Engineering Physics Institute; Professor

WADEHRA, JOGINDRA M.: Ph.D., New York University; M.S., University of Nebraska; M.Sc., B.Sc., University of Delhi; Professor

ZHOU, ZHIXIAN: Ph.D., Florida State University; B.S., Lanzhou University; Associate Professor

- Physics (M.A.) (http://bulletins.wayne.edu/graduate/college-liberal-arts-sciences/physics-astronomy/physics-ma/)
- Physics (M.S.) (http://bulletins.wayne.edu/graduate/college-liberal-arts-sciences/physics-astronomy/physics-ms/)
- Physics (Ph.D.) (http://bulletins.wayne.edu/graduate/college-liberal-arts-sciences/physics-astronomy/physics-phd/)

Astronomy

AST 5010 Astrophysics and Stellar Astronomy Cr. 3
Electromagnetic radiation and matter; solar characteristics; stellar distances; magnitudes; spectral classification; celestial mechanics; binary stars; stellar motions, structure and evolution; compact and variable stars; Milky Way Galaxy and interstellar medium; galaxies and clusters of galaxies; quasars; Hubble's Law; cosmology. Offered Every Other Winter.
Prerequisites: (PHY 2140 with a minimum grade of C- or PHY 2180 with a minimum grade of C-) and MAT 2010-6XXX with a minimum grade of C-
Equivalent: PHY 5010

AST 5100 Galaxies and the Universe Cr. 3
Exploration of the world of galaxies, starting with the Milky Way and moving outward to larger scales. Basic properties of galaxies: galaxy classification, structure, evolution, observations of Active Galactic Nuclei (AGN), Quasar, and Seyfert galaxies. Discovery of dark matter and black holes. Cosmology: origins of the universe in a hot big bang; its expansion history including recent evidence that the cosmic expansion is accelerating; the cosmic microwave background, and the ultimate fate of the universe. Capstone course for astronomy majors. Offered Winter.
Prerequisites: PHY 3300 with a minimum grade of C-

AST 6080 Survey of Astrophysics Cr. 3
This course provides an introduction to high-energy astrophysics with a focus on X-ray astronomy. We will cover the physics of X-ray emission and absorption in an astrophysical context, as well as discussing observational techniques used to detect X-rays. Bright X-ray emitting objects are some of the most extreme in the universe, and we will discuss objects including neutron stars, black holes, cataclysmic variables, supernovae and supernovae remnants, and galaxy clusters. Offered Every Other Year.
Equivalent: PHY 6080

Physics

PHY 5010 Astrophysics and Stellar Astronomy Cr. 3
Electromagnetic radiation and matter; solar characteristics; stellar distances; magnitudes; spectral classification; celestial mechanics; binary stars; stellar motions, structure and evolution; compact and variable stars; Milky Way Galaxy and interstellar medium; galaxies and clusters of galaxies; quasars; Hubble's Law; cosmology. Offered Every Other Winter.
Prerequisites: PHY 3300 with a minimum grade of C-
Equivalent: AST 5010

PHY 5015 Non-classical Physics for Educators Cr. 3
Development of relativity and quantum mechanics. Emphasis on nuclear physics and elementary particles. Required math: algebra and trigonometry. Offered for undergraduate credit only. Offered Winter.
Prerequisites: PHY 2130 with a minimum grade of D- and PHY 2140 with a minimum grade of D-

PHY 5100 Methods of Theoretical Physics I Cr. 3
Introduction to mathematical tools used in advanced courses in physics. Offered Fall.
Prerequisites: MAT 2030 with a minimum grade of C- and PHY 2180 with a minimum grade of C-

PHY 5200 Classical Mechanics I Cr. 4
Introduction to fundamental ideas: Newton's laws, notions of momentum, angular momentum, kinetic and potential energy, mechanical energy, conservation laws, friction and retardation forces, oscillations, resonances, gravitation, and introduction to the Lagrangian formalism. Offered Fall.
Prerequisites: PHY 2180 with a minimum grade of C- and PHY 5100 with a minimum grade of C- (may be taken concurrently)

PHY 5210 Classical Mechanics II Cr. 3
Accelerated reference frames, centrifugal and Coriolis forces, rigid body dynamics, motion of tops and gyroscopes, Lagrange's equations, constraints, Lagrange multipliers, general central force problem, stability of orbits, relativistic mechanics. Offered Winter.
Prerequisite: PHY 5200 with a minimum grade of C- and MAT 2150 with a minimum grade of C-

PHY 5340 Optics Cr. 3
Electromagnetic radiation; geometrical, physical, and modern optics. Offered Winter.
Prerequisites: (PHY 2140 with a minimum grade of C- and MAT 2030 with a minimum grade of C-), (PHY 2180 with a minimum grade of C- and PHY 3700 with a minimum grade of C-), (PHY 2140 with a minimum grade of C- and PHY 3700 with a minimum grade of C-), or (PHY 2180 with a minimum grade of C- and MAT 2030 with a minimum grade of C-)

PHY 5341 Optics Laboratory Cr. 2
Experiments involving geometrical, physical, and quantum optics. Offered Winter.
Prerequisites: ECE 5760 with a minimum grade of C (may be taken concurrently) and PHY 5340 with a minimum grade of C (may be taken concurrently)
Course Material Fees: $25

PHY 5460 Lasers for Medical Applications Cr. 3
Summarizes the wealth of recent research on the principles, technologies and application of lasers in diagnostics, therapy and surgery. Includes an overview of optics, optical components used in a typical laser, key principles of lasers and radiation interactions with tissue. The respective types of the laser (solid state, gas, dye, and semiconductor) are reviewed to provide an understanding of the wide diversity, and therefore, the large possible choice of these devices for a specific diagnosis, treatment, or surgery. Offered Winter.
Equivalent: BME 5460, ME 5465

PHY 5620 Electronics and Electrical Measurements Cr. 3
Theory of amplifier circuits, operational amplifiers, oscillators, digital electronics, analog and digital measurements. Offered Fall.
Prerequisites: ((PHY 2180 with a minimum grade of C- and PHY 2181 with a minimum grade of C-) or (PHY 2140 with a minimum grade of C- and PHY 2141 with a minimum grade of C-)) and PHY 5621 with a minimum grade of C- (may be taken concurrently)
Corequisite: PHY 5621

PHY 5621 Electronics and Electrical Measurements Laboratory Cr. 2
Laboratory measurements related to amplifier circuits, operational amplifiers, oscillators, and digital electronics. The lab will also cover analog and digital measurements and will require a final project. Offered Fall.
Corequisite: PHY 5620
Course Material Fees: $25

PHY 5750 Biological Physics Cr. 4
Introduction to applications of physics to molecular biology. Offered Fall.
Prerequisites: PHY 3700 with a minimum grade of C- and PHY 4700 with a minimum grade of C-

PHY 5990 Directed Study Cr. 1-3
Primarily for students who wish to continue in a field beyond material covered in regular courses, or who wish to study material not covered in regular courses, including certain research participation. Offered Every Term.
Repeatable for 6 Credits

PHY 6080 Survey of Astrophysics Cr. 3
This course provides an introduction to high-energy astrophysics with a focus on X-ray astronomy. We will cover the physics of X-ray emission and absorption in an astrophysical context, as well as discussing observational techniques used to detect X-rays. Bright X-ray emitting objects are some of the most extreme in the universe, and we will discuss objects including neutron stars, black holes, cataclysmic variables, supernovae and supernovae remnants, and galaxy clusters. Offered Every Other Year.
Equivalent: AST 6080

PHY 6260 Survey of Elementary Particle Physics Cr. 3
Introduces students to the discoveries and research methods of elementary particle physics. Topics covered can include elementary particle dynamics; relativistic kinematics; symmetries, introduction to quantum field theory; Feynman calculus; gauge theories; the standard model and proposed modifications; experimental evidence; survey of experimental methods, detector, accelerators and colliders. Methods of quantum mechanics are introduced, including scattering theory; spin; symmetry groups; bound states; time dependent and time independent perturbation theory. Builds on a knowledge of quantum physics studied in courses like PHY 6400. Offered Every Other Fall.
Prerequisite: PHY 6400 with a minimum grade of C
Restriction(s): Enrollment is limited to Undergraduate level students.

PHY 6270 Survey of Nuclear Physics Cr. 3
Introduces upper-level undergraduate majors in physics and other science, technology and mathematics fields to the discoveries and research methods of nuclear physics. Nuclear physics topics covered can include nuclear collisions; nuclear structure: liquid drop model, shell model; nucleon-nucleon interaction; quarks and the strong interaction; quark-gluon plasma; alpha, beta and gamma decay; and nuclear fusion. Nuclear astrophysics topics can include compact objects; stellar nucleosynthesis; nucleosynthesis in supernovae, neutron star collisions, and the big bang. Methods of quantum mechanics are introduced, including scattering theory; Born approximation; eikonal approximation; Glauber Model; WKB theory; time dependent and time independent perturbation theory. Builds on a knowledge of quantum physics studied in PHY 6400 and is in-part a sequel to that course. Offered Every Other Fall.
Prerequisite: PHY 6400 with a minimum grade of C
Restriction(s): Enrollment is limited to Undergraduate level students.

PHY 6290 Survey of Biophysics Cr. 3
Introduction to modern biophysics with emphasis on a physical understanding of biological structure and function; biological activity; biology and light; energy, thermodynamics and statistical mechanics in biology; and techniques of experimental biophysics. Offered Yearly.
Prerequisite: PHY 3300 with a minimum grade of C- and (MAT 2030 with a minimum grade of C- or PHY 3700 with a minimum grade of C-) and (PHY 4700 with a minimum grade of C- or PHY 3500 with a minimum grade of C-)
Restriction(s): Enrollment is limited to Undergraduate level students.

PHY 6400 Quantum Physics I Cr. 4
This course introduces upper-level undergraduate majors in physics and other science, technology and mathematics fields to the methods of quantum mechanics. Topics covered will include operators and their eigenfunctions; quantization rules; solution of Schrödinger equation in 1- and 3-dimensions; angular momentum; spin; bosons and fermions; and time-independent perturbation theory. The course builds on a knowledge of modern physics as studied in introductory courses such as PHY 3300. Mathematical methods will be introduced for application to specific quantum mechanics problems. These include: Linear algebra; boundary value problems in ordinary differential equations; separation of variables in partial differential equations; Fourier transforms; orthogonal functions; Laplacian in spherical and cartesian coordinates; Legendre Functions and Spherical Harmonics; operators in Hilbert space. Offered Winter.
Prerequisites: PHY 5100 with a minimum grade of C-, PHY 3300 with a minimum grade of C-, and MAT 2150 with a minimum grade of C-

PHY 6410 Quantum Physics II Cr. 3
Applications of quantum mechanics: atoms in electric and magnetic fields, multielectron atoms, molecules, quantum statistics, solids (band structure, magnetic properties), nuclei, fundamental forces and standard model. Offered Fall.
Prerequisites: PHY 6400 with a minimum grade of C-

PHY 6450 Introduction to Material and Device Characterizations Cr. 4
Lecture/laboratory; introduction to analytic and measurement techniques for characterizing and evaluating materials, especially for potential applicability in sensor and integrated devices. Techniques include diffraction and microscopy methods, electron spectroscopies, and electrical, optical and magnetic measurements. Offered for graduate credit only. Offered Winter.
Prerequisite: (PHY 7050 (may be taken concurrently) or ECE 5500 (may be taken concurrently) or ECE 5550 (may be taken concurrently))
Restriction(s): Enrollment is limited to Graduate level students.
Course Material Fees: $60

PHY 6480 Introduction to Quantum Computing Cr. 3
Serves as an introduction to quantum computing and brings together students with different backgrounds in mathematics, physics, chemistry, and computer science to foster interdisciplinary connections in the areas of quantum computing and quantum information. A strong background in linear algebra over the complex numbers as well as differential and integral calculus is required. Familiarity with quantum physics and complexity theory will be helpful, but it is not required. Offered Fall.
Equivalent: MAT 6480

PHY 6500 Thermodynamics and Statistical Physics Cr. 4
Laws of thermodynamics, thermodynamic equilibrium, applications of kinetic theory of gases, basic introduction to classical and quantum statistical description of physical systems with large numbers of particles. Offered Fall.
Prerequisites: PHY 5100 with a minimum grade of C- and PHY 3300 with a minimum grade of C-

PHY 6570 Smart Sensor Technology I: Design Cr. 4
Introduction to various types of sensors and the design of basic analog VLSI circuit building blocks. Offered Winter.
Equivalent: BME 6470, ECE 6570

PHY 6600 Electromagnetic Fields I Cr. 4
This course introduces upper-level undergraduate majors in physics and other science, technology and mathematics fields to the methods of electricity and magnetism. Topics covered will include electrostatics; solution of the Laplace equation; electric current; magnetic field of steady currents; electromagnetic induction; Maxwell Equations; and electromagnetic waves. The course builds on a knowledge of electromagnetic phenomena as studied in introductory courses such as PHY 2180. Mathematical methods will be introduced for application to specific electromagnetism problems, including spherical and cylindrical coordinates; vector calculus in 2 and 3 dimensions; Stokes and divergence integral theorems; solution of Laplace and Wave equations by separation of variables; uniqueness of solutions for linear PDE of Elliptic and Hyperbolic type; boundary and initial value problems; scalar and vector potentials. Offered Fall.
Prerequisite: PHY 5100 with a minimum grade of C- and PHY 5200 with a minimum grade of C- and MAT 2150 with a minimum grade of C-

PHY 6610 Electromagnetic Fields II Cr. 3
Continuation of PHY 6600: Maxwell equations, electromagnetism and relativity, optics, wave guides and transmission lines, radiation of EM waves. Offered Winter.
Prerequisite: PHY 6600 with a minimum grade of C-

PHY 6750 Applied Computational Methods Cr. 2
Development of concepts learned in PHY 3750 or PHY 3310 for computer applications in physics research, including applications in theoretical physics, data fitting, image analysis, and integration with experimental equipment. There will be opportunities for independent as well as group projects. Offered Fall.
Prerequisite: PHY 3750 with a minimum grade of C- or PHY 3310 with a minimum grade of C-

PHY 6780 Research Methods in Biomedical Physics Cr. 3
Satisfies General Education Requirement: Writing Intensive Competency
Introduction to laboratory experience in biomedical physics research. Capstone course for biomedical physics majors. Offered Winter.
Prerequisites: PHY 3700 with a minimum grade of C- and PHY 4700 with a minimum grade of C-

PHY 6850 Modern Physics Laboratory Cr. 2
Satisfies General Education Requirement: Writing Intensive Competency
Techniques and experiments in physics of atoms, atomic nuclei, molecules, the solid state and other areas that have advanced our modern understanding of physics. Offered Winter.
Prerequisites: PHY 3300 with a minimum grade of C-
Course Material Fees: $25

PHY 6860 Computational Physics Cr. 3
Introduction to use of computers to model physical systems; description of techniques in numerical analysis including linear algebra, integration, algebraic and differential equations, data analysis and symbolic algebra. Offered Fall.
Prerequisites: PHY 3310 with a minimum grade of C- or PHY 5100 with a minimum grade of C-

PHY 6991 Special Topics Cr. 1-4
Topics and prerequisites for each section to be announced in Schedule of Classes . More than one section may be elected in a semester. Offered for graduate credit only. Offered Yearly.
Restriction(s): Enrollment is limited to Graduate level students.
Repeatable for 4 Credits

PHY 6992 Physics Graduate Teaching Assistant Training Cr. 1
Students solve and discuss problems from calculus-based general physics courses in front of their peers and instructor, enhancing their ability to analyze, interpret and present the material in a clear, informative way. Offered for graduate credit only. Offered Fall.
Restriction(s): Enrollment is limited to Graduate level students.

PHY 6995 Professional Development Seminar in Physics Cr. 2
Introduction to the conduct, skills and ethics of a professional physicist or astronomer. Topics include: critical reading of scientific literature; research ethics and professional conduct; introduction to modern research topics in physics and research in the department of physics and astronomy; careers in physics and astronomy; scientific and proposal writing; and teamwork. Offered Yearly.
Repeatable for 4 Credits

PHY 7050 Survey of Condensed Matter Physics Cr. 3
Contemporary solid state physics dealing primarily with experiments in this area and with modern descriptive models of solids. Offered Winter.
Prerequisite: PHY 6400 with a minimum grade of C
Restriction(s): Enrollment is limited to Graduate level students.

PHY 7060 Survey of Elementary Particle Physics Cr. 3
This course introduces graduate students to the discoveries and research methods of elementary particle physics. Topics covered can include elementary particle dynamics; relativistic kinematics; symmetries, introduction to quantum field theory; Feynman calculus; gauge theories; the standard model and proposed modifications; experimental evidence; survey of experimental methods, detector, accelerators and colliders. Methods of quantum mechanics are introduced, including scattering theory; spin; symmetry groups; bound states; time dependent and time independent perturbation theory. The course builds on a knowledge of quantum physics studied in courses like PHY 6400. Offered Every Other Fall.
Prerequisite: PHY 6400 with a minimum grade of C
Restriction(s): Enrollment is limited to Graduate level students.

PHY 7070 Survey of Nuclear Physics Cr. 3
This course introduces graduate students to the discoveries and research methods of nuclear physics. Nuclear physics topics covered can include nuclear collisions; nuclear structure: liquid drop model, shell model; nucleon-nucleon interaction; quarks and the strong interaction; quark-gluon plasma; alpha, beta and gamma decay; and nuclear fusion. Nuclear astrophysics topics can include compact objects; stellar nucleosynthesis; nucleosynthesis in supernovae, neutron star collisions, and the big bang. Methods of quantum mechanics are introduced, including scattering theory; Born approximation; eikonal approximation; Glauber Model; WKB theory; time dependent and time independent perturbation theory. The course builds on a knowledge of quantum physics studied in courses like PHY 6400. Offered Every Other Fall.
Prerequisite: PHY 6400 with a minimum grade of C
Restriction(s): Enrollment is limited to Graduate level students.

PHY 7080 Survey of Astrophysics Cr. 3
This course provides an introduction to high-energy astrophysics with a focus on X-ray astronomy. We will cover the physics of X-ray emission and absorption in an astrophysical context, as well as discussing observational techniques used to detect X-rays. Bright X-ray emitting objects are some of the most extreme in the universe, and we will discuss objects including neutron stars, black holes, cataclysmic variables, supernovae and supernovae remnants, and galaxy clusters. Offered Every Other Year.
Restriction(s): Enrollment is limited to Graduate level students.

PHY 7090 Survey of Biophysics Cr. 3
Introduction to modern biophysics with emphasis on a physical understanding of biological structure and function; biological activity; biology and light; energy, thermodynamics and statistical mechanics in biology; and techniques of experimental biophysics. Offered Yearly.
Restriction(s): Enrollment is limited to Graduate level students.

PHY 7110 Methods of Theoretical Physics II Cr. 3
Complex variables and their applications. Homogeneous and inhomogeneous differential equations. Special functions such as gamma functions, Bessel functions, Legendre functions, Hermite functions and Laguerre functions. Fourier series. Offered Fall.
Prerequisite: PHY 5100 with a minimum grade of C
Restriction(s): Enrollment is limited to Graduate level students.

PHY 7200 Advanced Mechanics Cr. 3-4
Variational principles, central forces, transformation theory, Hamilton-Jacobi theory. Offered Winter.
Prerequisite: PHY 5210 with a minimum grade of C
Restriction(s): Enrollment is limited to Graduate level students.

PHY 7400 Quantum Mechanics I Cr. 3
Physical and mathematical principles of quantum mechanics. Schrodinger equation and its applications. Spin and angular momentum in quantum mechanics. The WKB approximation. Perturbation theory for time-independent and time-dependent cases. Offered Fall.
Prerequisite: PHY 6410 with a minimum grade of C and PHY 7110 (may be taken concurrently) with a minimum grade of C
Restriction(s): Enrollment is limited to Graduate level students.

PHY 7410 Quantum Mechanics II Cr. 3
Scattering theory. Partial wave expansion and perturbation theory. Bound states. Symmetry principles and conservation laws. The path integral formalism. Entanglement. Quantum computation. Charged particles in electromagnetic fields. Quantum theory of radiation. Relativistic one-particle equations Offered Winter.
Prerequisite: PHY 7400 with a minimum grade of C
Restriction(s): Enrollment is limited to Graduate level students.

PHY 7500 Statistical Mechanics Cr. 4
Classical and quantum statistical mechanics and applications. Offered Fall.
Prerequisite: PHY 6500 with a minimum grade of C and PHY 7400 with a minimum grade of C
Restriction(s): Enrollment is limited to Graduate level students.

PHY 7550 Advanced Condensed Matter Physics: Solid State Cr. 3
Current topics in condensed matter physics, including electronic band structure, magnetism, superconductivity, nanophysics, and the optical properties of solids. Offered Every Other Fall.
Prerequisite: PHY 7050 with a minimum grade of C and PHY 7110 with a minimum grade of C and PHY 7400 with a minimum grade of C
Restriction(s): Enrollment is limited to Graduate level students.

PHY 7560 Advanced Condensed Matter Physics: Soft Matter Cr. 3
Current topics in condensed matter physics, including the building blocks, structures, physical properties, and phase transitions in a variety of complex fluid systems such as simple liquids and liquid mixtures, colloids, polymers, liquid crystals, amphiphiles, and soft matter in living organisms. Offered Every Other Winter.
Prerequisite: PHY 7050 with a minimum grade of C and PHY 7110 with a minimum grade of C and PHY 7400 with a minimum grade of C
Restriction(s): Enrollment is limited to Graduate level students.

PHY 7580 Smart Sensor Technology II: Characterization and Fabrication Cr. 4
Integration of ongoing research in integrated technology of smart sensors. Design of smart sensor devices using computer simulation. Fabrication of smart sensor. Offered Spring/Summer.
Prerequisite: PHY 6570 with a minimum grade of B- or ECE 6570 with a minimum grade of B- or BME 6470 with a minimum grade of B-
Restriction(s): Enrollment is limited to Graduate level students.
Course Material Fees: $50
Equivalent: BME 7470, ECE 7570

PHY 7600 Electromagnetic Theory I Cr. 3
Microscopic and macroscopic Maxwell's equations, special relativity, Lagrangian and Hamiltonian formulation of EM theory, energy-momentum tensor, conservation laws, radiation, scattering, applications. Offered Winter.
Prerequisite: PHY 6610 with a minimum grade of C
Restriction(s): Enrollment is limited to Graduate level students.

PHY 7610 Electromagnetic Theory II Cr. 3
Continuation of PHY 7600. Offered Fall.
Prerequisite: PHY 7600 with a minimum grade of C
Restriction(s): Enrollment is limited to Graduate level students.

PHY 7850 Data Analysis Techniques Cr. 3
Foundations in probability and statistics used in physics, biophysics and astronomy, an extensive discussion of the notions of statistical and systematic uncertainties, data correction techniques, and basic Monte Carlo techniques. Offered Yearly.
Prerequisite: MAT 2030 with a minimum grade of C or PHY 6850 with a minimum grade of C or PHY 6750 with a minimum grade of C
Restriction(s): Enrollment is limited to Graduate level students.

PHY 7990 Directed Study Cr. 1-3
Application forms available in department office. Primarily for graduate students in physics who wish to study material not covered in regular courses. Offered Every Term.
Restriction(s): Enrollment is limited to Graduate level students.
Repeatable for 6 Credits

PHY 7996 Research in Physics Cr. 1-4
Offered Every Term.
Restriction(s): Enrollment is limited to Graduate level students.
Repeatable for 12 Credits

PHY 7999 Master's Essay Direction Cr. 1-3
Offered Every Term.
Restriction(s): Enrollment limited to students with a class of Candidate Masters; enrollment is limited to Graduate level students.

PHY 8800 Advanced Nuclear Physics Cr. 3
Research topics in nuclear physics such as: relativistic heavy ion physics, nuclear/nucleon models, and many body theory. Covers both theory and experimental methods. Offered Every Other Winter.
Prerequisite: PHY 7070 with a minimum grade of C and PHY 7110 with a minimum grade of C and PHY 7410 with a minimum grade of C
Restriction(s): Enrollment is limited to Graduate level students.

PHY 8810 Advanced Particle Physics Cr. 3
Advanced elementary particle physics including weak, electromagnetic, and strong interactions. Rudiments of experimental devices and techniques at level appropriate to both experimentally- and theoretically-oriented students. Offered Every Other Fall.
Prerequisite: PHY 7060 with a minimum grade of C and PHY 7110 with a minimum grade of C and PHY 7410 with a minimum grade of C
Restriction(s): Enrollment is limited to Graduate level students.

PHY 8850 Quantum Theory of Fields I Cr. 3
Introduction to quantum field theory, classical and path integral quantization of scalar, spinor, and vector fields, gauge theories, interactions and Feynman rules, modal field theories, Hubbard model, introduction to renormalization Suitable for both students of theory and experiment in the fields of nuclear, particle, and condensed matter physics and astrophysics. Offered Every Other Fall.
Prerequisite: PHY 7110 with a minimum grade of C and PHY 7410 with a minimum grade of C
Restriction(s): Enrollment is limited to Graduate level students.

PHY 8860 Quantum Theory of Fields II Cr. 3
Symmetry and symmetry breaking. Goldstone theorem and Higgs effect, renormalization group, collective phenomena, superfluids and superconductivity, the Standard Model of electroweak interactions, effective field theories. Appropriate for students in fields of nuclear, particle, condensed matter physics and astrophysics. Offered Every Other Winter.
Prerequisite: PHY 8850 with a minimum grade of C
Restriction(s): Enrollment is limited to Graduate level students.

PHY 8991 Special Topics Cr. 1-3
Topics and prerequisites for each section to be announced in Schedule of Classes . More than one topic may be elected in a semester. Offered Fall, Winter.
Restriction(s): Enrollment is limited to Graduate level students.
Repeatable for 12 Credits

PHY 8995 Colloquium Cr. 1
Must be elected every semester by all graduate physics students. Lectures given by external visitors and graduate faculty. Offered Fall, Winter.
Restriction(s): Enrollment is limited to Graduate level students.

PHY 8999 Master's Thesis Research and Direction Cr. 1-8
Offered Every Term.
Restriction(s): Enrollment limited to students with a class of Candidate Masters; enrollment is limited to Graduate level students.
Repeatable for 8 Credits

PHY 9990 Pre-Doctoral Candidacy Research Cr. 1-8
Research in preparation for doctoral dissertation. Offered Every Term.
Restriction(s): Enrollment is limited to Graduate level students.
Repeatable for 12 Credits

PHY 9991 Doctoral Candidate Status I: Dissertation Research and Direction Cr. 7.5
Offered Every Term.
Restriction(s): Enrollment is limited to Graduate level students.

PHY 9992 Doctoral Candidate Status II: Dissertation Research and Direction Cr. 7.5
Offered Every Term.
Prerequisite: PHY 9991 with a minimum grade of S
Restriction(s): Enrollment is limited to Graduate level students.

PHY 9993 Doctoral Candidate Status III: Dissertation Research and Direction Cr. 7.5
Offered Every Term.
Prerequisite: PHY 9992 with a minimum grade of S
Restriction(s): Enrollment is limited to Graduate level students.

PHY 9994 Doctoral Candidate Status IV: Dissertation Research and Direction Cr. 7.5
Offered Every Term.
Prerequisite: PHY 9993 with a minimum grade of S
Restriction(s): Enrollment is limited to Graduate level students.

PHY 9995 Candidate Maintenance Status: Doctoral Dissertation Research and Direction Cr. 0
Offered Every Term.
Restriction(s): Enrollment is limited to Graduate level students.
Course Material Fees: $384.7
Repeatable for 0 Credits