

# PHYSICS (PHYS)

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## PHYS 510: General Relativity I

3 Credits

Foundations of general relativity, elements of differential geometry, Einstein's equation, Newtonian limit, gravity waves, Friedmann cosmologies and Schwarzschild solution.

**Prerequisite:** PHYS 557

## PHYS 511: Topics in General Relativity

3 Credits

Selected topics from: Cauchy problem, Hamiltonian formulation, positive energy theorems, asymptotics, gravitational radiation, singularity theorems, black-holes, cosmology, observational tests.

**Prerequisite:** PHYS 510

## PHYS 512: Quantum Theory of Solids I

3 Credits

Electrons in periodic potentials; single electron approximations; lattice dynamics; electrical, optical, and magnetic properties of solids; transport theory.

**Prerequisite:** PHYS 412; Concurrent: PHYS 517

## PHYS 513: Quantum Theory of Solids II

3 Credits

Electron-phonon interaction, BCS theory; Landau Fermi-liquid theory; disorder and localized states; spin-wave theory; many-body theory.

**Prerequisite:** PHYS 512

## PHYS 514: Physics of Surfaces, Interfaces, and Thin Films

3 Credits

This course focuses on interfacial and surface phenomena; structural, electronic, vibrational and thermodynamic properties; physisorption and chemisorption; phase transitions and ultrathin film nucleation; and growth phenomena.

**Prerequisite:** PHYS 412

## PHYS 515: Density Functional Theory and Practice

3 Credits

This course gives students an overview of the theory and practice of calculations performed with Density Functional Theory (DFT). DFT is a powerful tool to calculate the structural and electronic properties of collections of atoms. The course emphasizes the practical aspects of the calculations and the theory will be only described as necessary to understand and perform correct calculations. The target audience of the course is students of Physics, Chemistry, Materials Science, Chemical or Mechanical Engineering, and other science/engineering disciplines that need to learn to perform calculations based on DFT with a minimum of exposure to the theoretical details underlying this technique.

Cross-listed with: CHE 515

## PHYS 517: Statistical Mechanics

3 Credits

Thermodynamics, classical and quantum statistics; Bose and Fermi gases; Boltzmann transport equation; phase transitions, critical phenomena; Ising model.

**Prerequisite:** PHYS 561

## PHYS 518: Critical Phenomena and Field Theory

3 Credits

Critical phenomena using field theoretical and renormalization group techniques; solvable statistical models and conformal field study; fluctuations and random processes. PHYS 518 Critical Phenomena and Field Theory (3) The application of field theoretical methods, in particular, the renormalization group approach, has profoundly influenced our understanding of the physics of continuous phase transitions. In particular, they reveal the origin of universality between seemingly unrelated phase transitions, and the reason for the failure of the Landau Ginzburg theory close to the critical point. This course will begin with the concepts of the order parameter and spontaneous symmetry breaking, and the shortcomings of the Landau Ginzburg theory that neglects fluctuations of the order parameter. Subsequently, we will introduce field theoretical techniques and Feynman diagrams, and the basic foundations of the renormalization group method for integrating out rapidly fluctuating modes of the order parameter. These concepts will be applied to various classes of phase transitions, including the Heisenberg ferromagnet, nonlinear sigma model, and the Kosterlitz-Thouless model. Epsilon expansion will be performed in detail starting from both four and two dimensions, and a connection will be made to experiments, such as superfluid transition in thin helium films. No prior knowledge of field theory is required. The course grade will be based upon homework assignments and a term paper.

**Prerequisite:** PHYS 517

## PHYS 524: Physics of Semiconductors and Devices

3 Credits

Electronic structure, optical and transport properties of crystalline and amorphous semiconductors, quantum wells, superlattices; quantum devices; quantum Hall effect.

**Prerequisite:** PHYS 412

## PHYS 525: Methods of Theoretical Physics I

3 Credits

Complex variables, Hilbert spaces, linear operators, calculus of variations, Fourier analysis, Green's functions, distributions, differential equations, and special functions.

## PHYS 526: Methods of Theoretical Physics II

3 Credits

Finite and Lie groups, representations and application to condensed matter and particle physics; selected topics from differential geometry.

**Prerequisite:** PHYS 525

PHYS 527: Computational Physics and Astrophysics

3 Credits

This course provides an advanced overview of applications of numerical methods and computer programming to physics and astrophysics. Numerical calculations provide a powerful tool for understanding physical phenomena, complementing laboratory experiment and analytical mathematics. The main objectives of the course are: to survey the computational methods used for modeling physical and astrophysical systems; to apply the computational methods to solve real world problems in physics and astrophysics; to assess the reliability of numerical results using convergence tests and error estimates; and to use scientific visualization as a tool for computer programming development and for physical understanding of numerical results. Strong programming skill in any of the common programming languages such as C, C++, or Python, is highly recommended.

**Recommended Preparations:** Strong programming skills are highly recommended.

Cross-listed with: ASTRO 527

PHYS 529: Neural Control Engineering

3 Credits

The ability to use formal control theory to observe and control neuronal systems is rapidly becoming more feasible as our models of neural systems become more realistic and as our advances in nonlinear Kalman filtering become more sophisticated. This course will explore the cutting edge of nonlinear state estimation of neuronal systems and the construction of control algorithms based on that state estimation. We will give an overview of several canonical neuroscience models, which represent experimental systems that can be controlled: the Hodgkin-Huxley equations, their reduction with the Fitzhugh-Nagumo equations, the Wilson-Cowan model of cortex, and recent models of Parkinson's disease. We will then apply nonlinear state estimation to measurements from such systems and construct control algorithms that interact with such models.

**RECOMMENDED PREPARATIONS:** Students without a background including calculus, differential equations, and linear algebra should consult with the instructor.

PHYS 530: Theoretical Mechanics

3 Credits

Newtonian mechanics, noninertial coordinate system, Lagrangian mechanics, small oscillations, Hamiltonian formulation, canonical transformations, Hamilton-Jacobi theory, dynamical systems.

**Prerequisite:** PHYS 419

PHYS 541: Elementary Particle Phenomenology

3 Credits

Baryons and mesons; leptons and quarks; electromagnetic and weak interactions and their unification; quantum chromodynamics; experimental techniques.

**Prerequisite:** PHYS 562

PHYS 542: Standard Model of Elementary Particles Physics

3 Credits

Weinberg-Salam model of electroweak interactions, spontaneous symmetry breaking, quantum chromodynamics; selected topics from grand unified theories and superstring theory.

**Prerequisite:** PHYS 564

PHYS 545: Cosmology

3 Credits

Modern cosmology of the early universe, including inflation, the cosmic microwave background, nucleosynthesis, dark matter and energy. ASTRO (PHYS) 545 Cosmology (3) Cosmology is the scientific study of the universe as a whole: its physical contents, principal physical processes, and evolution through time. Modern cosmology, which began in the early 20th century, is undergoing a renaissance as a precision science as powerful ground- and space-based telescopes allow us to observe the formation of the first stars, galaxies and galaxy clusters; the echoes of the inflationary epoch as they are impressed upon the cosmic microwave background; and evidence for and clues to the nature of the mysterious dark energy, which is driving the accelerating expansion of the universe. This course will introduce students to the key observations and the theoretical framework through which we understand the physical cosmology of the early universe.

Cross-listed with: ASTRO 545

PHYS 555: Polymer Physics I

3 Credits

Introduction to the fundamental concepts needed to understand the physics applicable to polymer melts, solutions and gels. MATSE (PHYS) 555 Polymer Physics I (3) This course develops fundamental understanding of the conformations of polymers in solution and melt states. We start with ideal chains that have random walk statistics. Next excluded volume is introduced to understand the self-avoiding walk conformation and collapsed conformation of real chains. The behavior ideal and real chains are studied in extension, compression and adsorption. While positive excluded volume leads to swelling, negative excluded volume leads to collapse and phase separation. The phase behavior of polymer mixtures and solutions is described in detail. Semidilute solutions are understood in terms of two length scales where each chain changes its conformational statistics. Scattering is used to determine the conformation of chains, their molar mass and their interactions with surroundings. Percolation theory is introduced to model the statistics of random branching and gelation. The rubber elasticity of fully developed networks is understood in terms of the stretching laws for network chains. Entanglement effects, swelling and viscoelasticity are discussed in detail. Once the conformations of polymers are understood, dynamics of polymer liquids are considered. In dilute solutions hydrodynamic interactions dominate and the viscoelasticity predicted by the Zimm model is derived. In unentangled melts of short chains, hydrodynamic interactions are screened and the Rouse model is used to understand viscoelasticity. Unentangled polymers in semidilute solutions have Zimm dynamics on small length scales and Rouse dynamics on longer length scales. Dynamic scattering techniques are discussed for measuring polymer dynamics. Entanglement effects are described using the tube model, where surrounding chains confine the motion of a given polymer to a tube-like region. The effects of concentration, chain length

and polydispersity of linear chain polymer liquids are discussed in detail. The effects of branching on polymer dynamics are introduced at the level of simple structures such as star polymers and comb polymers. The course assumes some prior knowledge of polymers, usually obtained through an introductory undergraduate course. The students should attain a working understanding of the basic concepts of polymer physics in this course, allowing them to tackle more difficult problems in their research. Such skills are reinforced through homework and take-home examinations.

Cross-listed with: MATSE 555

PHYS 557: Electrodynamics

3 Credits

Special relativity, electromagnetic fields, Maxwell's equations, conservation laws, electrostatics and magnetostatics. PHYS 557 Electrodynamics (3) The first half of the course starts from special relativity and uses Hamilton's principle to derive relativistic dynamics and Maxwell's equations. This approach, developed by Landau and Lifshitz, sets classical electrodynamics in a broad base of theoretical physics, and provides insights to solving many interesting problems that might be hard to solve starting from the traditional approach of deriving Maxwell's equations empirically through Coulomb's law, the law of Biot and Savart, Faraday's law, and Maxwell's inclusion of displacement current. The second half is based on the classic textbook by Jackson, and is devoted to application of electrodynamics in various settings. This includes dynamics of charged particles in given electromagnetic fields, with special emphasis on problems with symmetry and the guiding center dynamics. Examples of such topics include electromechanical problems with the use of Lagrangian; fields generated by given distributions of charges and currents, especially for case of small sources, and the use of multiple expansions; polarization and magnetization, and Maxwell's equations in continuous media; boundary value problems; electromagnetic waves with single frequency in vacuum and medium; wave guides and resonant cavities; the generation of electromagnetic radiation.

**Prerequisite:** PHYS 400

PHYS 559: Graduate Laboratory

2 Credits

Study and applications of techniques and instrumentation used in modern physics laboratories.

PHYS 561: Quantum Mechanics I

3 Credits

Postulates of quantum mechanics, Hilbert space methods, one dimensional potentials, spin systems, Harmonic oscillator, angular momentum, Hydrogen atom.

**Prerequisite:** PHYS 410

PHYS 562: Quantum Mechanics II

3 Credits

Addition of angular momenta, perturbation theory, variational principle, scattering theory, density matrices, identical particles, interpretations of quantum mechanics, Dirac theory.

**Prerequisite:** PHYS 561

PHYS 563: Quantum Field Theory I

3 Credits

Canonical and functional integral quantization of relativistic and non-relativistic field theories; Feynman diagrams; spontaneous symmetry breaking; renormalization group.

**Prerequisite:** PHYS 562

PHYS 564: Quantum Field Theory II

3 Credits

Abelian and non-Abelian gauge theories; renormalization group and operator product expansions; BRST quantization; scattering theory, other related topics.

**Prerequisite:** PHYS 563

PHYS 565: Interface of General Relativity and Quantum Physics

3 Credits

Limitations of perturbative methods, conceptual problems; selected topics from black hole thermodynamics, canonical quantum gravity, loop space methods and string-theory.

**Prerequisite:** PHYS 510 , PHYS 563

PHYS 570: Particle Astrophysics

3 Credits

Particle astrophysics is a discipline at the interface between physics and astronomy, which has undergone tremendous growth in the 21st century, with the commissioning and exciting results from very large facilities detecting the highest energy cosmic rays, neutrinos, gravitational waves, and gamma-rays. There is a rapid and ongoing expansion of the understanding of these radiations, their physics and their sources, which include supernovae, gamma-ray bursts, and active galactic nuclei, and there are major new facilities aimed at characterizing particle properties of dark matter and its cosmological effects. Students will be given an overview of the basics of particle astrophysics and to the latest data and its interpretation, stressing issues currently discussed by the community, with particular attention on major projects in which Penn State faculty are involved. The course is designed for graduate students in physics and astronomy and astrophysics, being also appropriate for students in nuclear engineering or related disciplines.

**Prerequisites:** ASTRO 502; PHYS 400; PHYS 406 PHYS 557

PHYS 571: Modern Atomic Physics

3 Credits

Light-atom interactions, atomic structure, laser cooling and trapping, interferometry, and Bose-Einstein condensation. PHYS 571 Modern Atomic Physics (3) Students will learn the physics behind most of the major recent developments in the field of atomic physics, at the level required for research at the graduate level. Material to be covered will include selected topics from the following list: Light-atom interactions, atomic structure, laser cooling, atom trapping and atomic optics, atom interferometry, precision measurements with atoms, quantum computing with atoms, atomic Bose-Einstein condensates, degenerate Fermi

gases, reduced dimensionality systems, simulating condensed matter physics with atoms. Students will enhance their technical writing and presentation skills. Students will use the background they have acquired to develop an oral presentation related on a research advance related to modern atomic physics.

**Prerequisite:** PHYS 411 , PHYS 561 , or CHEM 565

PHYS 572: Laser Physics and Quantum Optics

3 Credits

Theory of modern lasers, non-linear and quantum optics, photon statistics, laser spectroscopies, pulsed lasers. PHYS 572 Laser Physics and Quantum Optics (3) Students will learn the basic physics of lasers, how they work and how they are used, primarily for physics research at the graduate level. They will become familiar with a broad array of the most important topics of laser physics including mode competition, pulsed lasers, pulse propagation, non-linear laser spectroscopy, laser stabilization, and the quantum nature of laser light. Students will enhance their technical writing and presentation skills. Students will use the background they have acquired to develop an oral presentation related on a research advance related to lasers.

**Prerequisite:** PHYS 410 , PHYS 561 , or CHEM 565

PHYS 580: Elements of Network Science and Its Applications

3 Credits

Introduction to elements of network theory used to describe and model complex networks; applications in social, biological, and technological networks. PHYS 580 Elements of Network Science and Its Applications (3) Network Science is the study of network representations of physical, biological, and social phenomena leading to predictive models of these phenomena. This class will focus on four main questions asked by network science: (i) How do we use data analysis methods to determine or infer the interaction graphs underlying complex systems? (ii) How can we characterize the organizational features of large-scale networks? (iii) What are the mechanisms that determine the common topological features of a wide variety of networks? (iv) To what extent does the organization of the interaction network underlying a complex system determine the dynamical behavior (e.g. steady state or oscillations) of the system? Applications in social, biological and technological networks will be examined. As Network Science is an interdisciplinary field of research, the course is open and should be of interest to a wide range of graduate students in degree programs in physics, social sciences, life sciences, mathematics, engineering, and computer science.

**Prerequisite:** knowledge of basis calculus

PHYS 590: Colloquium

1-3 Credits/Maximum of 3

Continuing seminars that consist of a series of individual lectures by faculty, students, or outside speakers.

PHYS 596: Individual Studies

1-9 Credits/Maximum of 9

Creative projects, including nonthesis research, which are supervised on an individual basis and which fall outside the scope of formal courses.

PHYS 597: Special Topics

1-9 Credits/Maximum of 9

Formal courses given on a topical or special interest subject which may be offered infrequently.

PHYS 600: Thesis Research

1-15 Credits/Maximum of 999

No description.

PHYS 601: Ph.D. Dissertation Full-Time

0 Credits/Maximum of 999

No description.

PHYS 602: Supervised Experience in College Teaching

1-3 Credits/Maximum of 6

Supervised experience in teaching and orientation to other selected aspects of the profession at The Pennsylvania State University

PHYS 610: Thesis Research Off Campus

1-15 Credits/Maximum of 999

No description.

PHYS 801: Foundations of Teaching in Physics

1 Credits

An overview of the science of teaching and learning physics. This course will prepare physics graduate students to become both better learners and teachers through reading about, discussing, observing and practicing inclusive, evidence-based instructional and learning strategies.