APPLIED PHYSICS

Degree Types: PhD

The Applied Physics Graduate Program (https://www.appliedphysics.northwestern.edu/) is a joint program between the McCormick School of Engineering & Applied Science and the Weinberg College of Arts & Sciences, and spans multiple departments including Physics & Astronomy, Chemistry, Electrical & Computer Engineering and Materials Science & Engineering. The program offers interdisciplinary PhD research opportunities for graduate students with a strong undergraduate background in Physics.

The Applied Physics Program is designed to allow students to complete their PhD studies in as little as five years. Students can complete the required courses during the first year, allowing them to fully focus their efforts on research starting as of the second year. Unlike programs based in a single department, Applied Physics students can take advantage of the scholarships, learning opportunities, and other resources offered by both the McCormick School of Engineering, the Weinberg College of Arts & Sciences, and nearby Argonne National Laboratory and Fermi National Accelerator Laboratory.

The program prepares graduates for professional careers in science and technology, either in academics or in industry, and seeks to ensure that our graduates recognize and take advantage of scientific and technological opportunities wherever they may arise.

Additional resources:

- Program website (https://www.appliedphysics.northwestern.edu/)
- Program handbook(s)

Degrees Offered

- Applied Physics PhD (https://catalogs.northwestern.edu/tgs/applied-physics/applied-physics-phd/)

Learning objective(s)/Students should be able to…

- Contribute original research to scholarly community and apply appropriate research methodology and analyses, given particular research question.
- Create and communicate professional development plan.
- Develop classroom activities for a specific discussion section.
- Read, understand, and critically discuss topical scientific literature, and demonstrate expertise in underlying fundamentals.
- Give oral presentation of own research results to an audience of peers and faculty (i.e. subject matter experts and scientists outside own field). Articulate broader impacts of research.
- Motivate/describe proposed research and highlight possibilities for discovery and advancement of knowledge.

Applied Physics Course Descriptions

APP_PHYS 499-0 Independent Study (1-3 Units)
See Dept for section number - May be repeated for credit. Permission of instructor required.

APP_PHYS 590-0 Research (1-3 Units)
See Dept for section number - Independent investigation of selected problems pertaining to thesis or dissertation. May be repeated for credit.

Computational Methods of Applied Physics

CHEM 448-0 Computational Chemistry (1 Unit)
The theory and application of molecular electronic structure methods, techniques for determining vibrational eigenfunctions and scattering properties, and molecular mechanics, molecular mechanics and Monte Carlo calculations. Included are extensive applications to chemical problems using Unix workstations.

CHEM_ENG 451-0 Applied Molecular Modeling (1 Unit)
Introduction to modern computational methods for calculating properties of reaction systems, as well as thermodynamics, transport, and structural properties of materials.

ELEC_ENG 435-0 Deep Learning: Foundations, Applications, and Algorithms (1 Unit)
The course covers the fundamentals of deep learning and numerical optimization, with many application examples.

ELEC_ENG 463-0 Adaptive Filters (1 Unit)
Applications of adaptive filtering, autoregressive and moving average processes, linear prediction, Wiener filter, Least Mean Square (LMS) algorithm, lattice filter, least squares filtering, Kalman filter, convergence analysis.

ELEC_ENG 475-0 Machine Learning: Foundations, Applications, and Algorithms (1 Unit)
The course covers the fundamentals of machine learning and numerical optimization, with many application examples.

ELEC_ENG 495-0 Special Topics in Electrical Engineering (1 Unit)

ES_APPM 446-2 Numerical Solution of Partial Differential Equations (1 Unit)
Course on using spectral methods to solve partial differential equations. We will cover the exponential convergence of spectral methods for periodic and non-periodic problem, and a general framework to efficiently solve nearly arbitrary PDEs with spectral methods. The course mixes discussion of theoretical aspects of spectral methods with their practical application using Python. The students will learn the algorithms underpinning the Dedalus spectral code, and how to use Dedalus.

MAT_SCI 458-0 Atomic Scale Computational Materials Science (1 Unit)
Theory and application of atomic-scale computational materials tools to model, understand, and predict the properties of real materials.

MECH_ENG 417-0 Multi-scale Modeling and Simulation in Solid Mechanics (1 Unit)
Introduction to modern computational methods such as molecular dynamics and continuum mechanics. Applications will be nanostructure and polymer composites.

MECH_ENG 418-0 Multi-Scale Modeling and Simulation in Fluid Mechanics (1 Unit)
Introduction to modern computational methods such as molecular dynamics and continuum mechanics. Applications will be Biological and bioinspired materials: Biopolymer, Protein, DNA, Lipids.

MECH_ENG 423-0 Intro to Computational Fluid Dynamics (1 Unit)
Discretization methods, solution of Navier-Stokes equations, algorithms for fluid flow problems (pressure-based algorithms, fractional time-stepping schemes, etc.), three-dimensional, steady, unsteady flows.

MECH_ENG 426-1 Advanced Finite Element Methods I (1 Unit)
Discretization methods, weak and strong forms, Newton methods for constrained and unconstrained problems, explicit methods, continuation methods.

Prerequisite: MECH_ENG 327-0 or equivalent.

MECH_ENG 426-2 Advanced Finite Element Methods II (1 Unit)
Alternative mesh descriptions, Langrangian, Eulerian, and arbitrary Langrangian Eulerian, meshless methods and particle methods, continuum based shell formations, contract-impact.
Prerequisite: MECH_ENG 426-1.

PHYSICS 430-0 Nonlinear Dynamics & Chaos (1 Unit)
This course covers the mathematics of nonlinear oscillations, fractal geometry, chaotic dynamics, the dynamics of complex systems, and physics applications of these ideas. Projects involving applications of nonlinear dynamics and chaos are integral to this course.
Prerequisites: Undergraduate level classical mechanics and familiarity with computer programming.

PHYSICS 465-0 Advanced Topics in Nonlinear Dynamics (1 Unit)
Specialized lectures on current research topics in nonlinear dynamics.

PHYSICS 441-0 Statistical Methods for Physicists and Astronomers (1 Unit)
Data analysis in the modern age requires familiarity of many concepts and methods from statistics. This course provides an introduction to the basics as well as exposure to some of the most advanced techniques. The emphasis will be on practical problems from physics and astronomy, rather than on theory or on statistical methods from other fields. Prior knowledge of statistics is not required.

COMP_SCI 449-0 Deep Learning (1 Unit)
Deep learning is a branch of machine learning based on algorithms that try to model high-level abstract representations of data by using multiple processing layers with complex structures. Some representations make it easier to learn tasks (e.g., face recognition or spoken word recognition) from examples. One of the promises of deep learning is replacing handcrafted features with efficient algorithms for unsupervised or semi-supervised feature learning and hierarchical feature extraction. In this course students will study deep learning architectures such as autoencoders, , convolutional deep neural networks, and recurrent neural networks. They will read original research papers that describe the algorithms and how they have been applied to fields like computer vision, automatic speech recognition, and audio event recognition. For projects, students can work on their own or in groups (recommended) to write a codebase that reproduces a landmark research paper. This course is aimed at advanced undergraduates, masters, and PhD students.
Prerequisites: CS 349 or CS PhD or Instructor permission.

Experimental Methods of Applied Physics

MECH_ENG 433-0 Advanced Mechatronics (1 Unit)
Hands-on laboratory class on design and control of electromechanical systems. Real time operating systems, analog and digital electronics, sensors and actuators. Lectures, labs, and projects.

MAT_SCI 460-0 Electron Microscopy (1 Unit)
Electron optics. Kinematic and dynamical theory of electron diffraction. Introduction to microanalysis.

MAT_SCI 461-0 Diffraction Methods in Material Science (1 Unit)
Advanced theory of diffraction. Diffraction effects accompanying imperfections. Thermal motion, cold-work, formation of solid solutions, transformations, liquids, gases, dynamic scattering.

MAT_SCI 465-0 Advanced Electron Microscopy & Diffraction (1 Unit)
Theories of electron diffraction; theories of diffraction contrast and their application to lattice disorder; phase transformation. Current topics in electron and other charged-particle microscopy.

MAT_SCI 466-0 Analytical Electron Microscopy (1 Unit)
Diversity of analytical techniques in modern TEM, fundamental concepts in quantitative x-ray, EELS, CBED microanalysis, advanced AEM instrumentation, techniques and applications to physical and life sciences.

ELEC_ENG 495-0 Special Topics in Electrical Engineering (1 Unit)

Other Required Course Descriptions

MAT_SCI 401-0 Chemical & Statistical Thermodynamics of Materials (1 Unit)
Chemical thermodynamics via analytical and statistical approaches, including chemical potentials, conditions for equilibrium, distribution functions, ideal and regular solutions, and phase diagrams. Graduate core course.

MAT_SCI 405-0 Physics of Solids (1 Unit)
Reciprocal lattice representation, diffraction, Brillouin zone construction, bonding, lattice vibrations, phonon dispersion, and energy band structure of solids. Graduate core course.

PHYSICS 411-1 Methods of Theoretical Physics (1 Unit)
The topics covered will include: techniques for the solution of differential equations; approximations such as the method of steepest descent; techniques for integration; the special functions of mathematical physics; usage of Greens functions and eigenfunctions to solve differential equations; introduction to groups and group representations; probability and statistics (time permitting).

PHYSICS 412-1 Quantum Mech (1 Unit)
1.Vector spaces, linear operators, Hermitian operators, stationary states, bound states, harmonic oscillator, symmetry and conservation laws, intrinsic spin, Stern-Gerlach experiment, and spherically symmetric potentials. 2. Schrödinger's equation, electromagnetic potentials, approximation methods, variational principles, Dirac's theory of the electron, electron spin, magnetic moment of the electron, and fine structure of hydrogen. 3. Identical particles, exchange symmetry, atomic and molecular structure, coherent states, time-dependent perturbations, transition amplitudes, spontaneous emission, photoelectric effect, scattering theory, and light scattering.

PHYSICS 412-2 Quantum Mechanics (1 Unit)
1.Vector spaces, linear operators, Hermitian operators, stationary states, bound states, harmonic oscillator, symmetry and conservation laws, intrinsic spin, Stern-Gerlach experiment, and spherically symmetric potentials. 2. Schrödinger's equation, electromagnetic potentials, approximation methods, variational principles, Dirac's theory of the electron, electron spin, magnetic moment of the electron, and fine structure of hydrogen. 3. Identical particles, exchange symmetry, atomic and molecular structure, coherent states, time-dependent perturbations, transition amplitudes, spontaneous emission, photoelectric effect, scattering theory, and light scattering.

PHYSICS 414-1 Electrodynamics (1 Unit)
First quarter of a two-quarter class on Electrodynamics. Topics covered: Principles of Special Relativity and invariance. Relativistic electrodynamics as a classical field theory and action principles: for point particles, scalar fields, and vector fields, including Lagrangian formulation, principle of least action, symmetry principles, gauge invariance, the electromagnetic field tensor, covariant equations of electrodynamics and mechanics. Constant electromagnetic fields.

PHYSICS 416-0 Introduction to Statistical Mechanics (1 Unit)
Statistical mechanics and probability. Microstates and macrostates. Thermodynamic limit. Ensembles: microcanonical, canonical, grand canonical. Classical ideal gas: Maxwell-Boltzmann distribution. Quantum

gases: Fermi-Dirac and Bose-Einstein distributions. Thermodynamic potentials. Interacting systems. Phase diagrams and phase transitions.

PHYSICS 422-1 Condensed-Matter Physics (1 Unit)
1. Periodic potentials, x-ray diffraction; electrons in metals: semiclassical approximation, Fermi surface, and band structure; electronic, electrical, and thermal transport; Boltzmann equation; electron-electron interactions. 2. Phonons: classical and quantum theory; electron-phonon interaction and scattering; optical properties of solids; intrinsic and extrinsic semiconductors; heterostructures and quantum Hall effect. 3. In-depth treatment of selected topics, such as diamagnetism, paramagnetism, ferromagnetism, and formation of local moments. Phenomenological theory of superconductivity, transport and magnetic properties of superconductors, and superconducting devices.

GEN_ENG 519-0 Responsible Conduct for Research Training (0 Unit)
The primary focus of this course will be on education in the responsible conduct of research (RCR), especially as it pertains to the engineering disciplines. Ethical and moral reasoning will be developed through analysis of case studies on the topics of conflict of interest, mentoring and lab management, collaborative research, data ownership and management, peer review, authorship, misconduct and the processes for handling misconduct.

PHYSICS 519-0 Responsible Conduct of Research Training (0 Unit)

CHEM 519-0 Responsible Conduct of Research Training (0 Unit)
The goal of Responsible Conduct of Research (RCR) training is for researchers to perform the most ethical research possible. RCR training is critical to prepare undergraduate students, graduate students, and postdoctoral researchers for ethical challenges that may arise when conducting research. RCR is mandatory for all Department of Chemistry researchers. Undergraduate researchers are required to complete the on-line course only.