PHYSICS

https://www.physics.northwestern.edu/

Degree Types: PhD, MS

Graduate Programs in Physics (https://www.physics.northwestern.edu/graduate) prepare students for careers in research, teaching, or industry. Students first acquire a strong theoretical background in quantum mechanics, statistical physics, electrodynamics, and classical mechanics.

Our department is particularly strong in multi-disciplinary research, with joint faculty in materials science, chemistry, and electrical engineering. Theoretical research in many fields is carried out with the aid of parallel supercomputers on campus and at the National Center for Supercomputing Applications in Champaign, Illinois. We also have strong ties to the Argonne National Laboratory, Fermi National Accelerator Laboratory, and ground-based observational facilities around the nation.

It is not unusual for students to conduct the bulk of their research with physicists outside the department, and in some cases outside the nation.

Degrees Offered

- Physics MS (https://catalogs.northwestern.edu/tgs/physics/physics-ms)
- Physics PhD (https://catalogs.northwestern.edu/tgs/physics/physics-phd)

Physics Courses

PHYSICS 411-0 Classical Mechanics (1 Unit)
Newtonian mechanics, conservation laws, and rigid-body dynamics; variational principle; Lagrangians, constraints, symmetry, conservation laws, non-potential forces, scattering, and linear oscillations; Hamiltonians, Poisson brackets, perturbation theory; and continuum dynamics.

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 412-3 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 412-4 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)
1. Electrostatics, boundary-value problems, multipole, electrostatics of macroscopic media, conductors and dielectrics, magnetostatics, Maxwell's equations, electromagnetic waves and gauge transformations, and conservation laws. 2. Special theory of relativity, Lorentz transformations, covariant formulation of electrodynamics, electrodynamics of charged particles, radiation by moving charges, retarded potentials, Cerenkov radiation, synchrotron radiation, and bremsstrahlung.

PHYSICS 414-2 Electrodynamics (1 Unit)
1. Electrostatics, boundary-value problems, multipole, electrostatics of macroscopic media, conductors and dielectrics, magnetostatics, Maxwell's equations, electromagnetic waves and gauge transformations, and conservation laws. 2. Special theory of relativity, Lorentz transformations, covariant formulation of electrodynamics, electrodynamics of charged particles, radiation by moving charges, retarded potentials, Cerenkov radiation, synchrotron radiation, and bremsstrahlung.

PHYSICS 416-0 Introduction to Statistical Mechanics (1 Unit)
PHYSICS 420-0 Statistical Physics (1 Unit)
Correlation functions, response theory, spontaneous symmetry breaking, phase transitions, fluctuations, and critical phenomena. Optionally: topics from condensed-matter physics, or nonequilibrium processes relevant to biophysics and economics.

PHYSICS 421-0 Introduction to Superconductivity (1 Unit)
Lectures and experimental demonstrations on the theory and phenomenology of superconductivity and its applications. No graduate prerequisites.

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.

PHYSICS 422-2 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.
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PHYSICS 422-3 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.

PHYSICS 424-1 Particle Physics (1 Unit)
PHYSICS 424-2 Particle Physics (1 Unit)
PHYSICS 426-0 Nonlinear Optics (1 Unit)
Nonlinear optical susceptibilities; wave propagation and coupling in nonlinear media; harmonic, sum, and difference frequency generation; parametric amplification and oscillation; phase-conjugation via four-wave mixing; self-phase modulation and solitons.

PHYSICS 427-0 Quantum Optics (1 Unit)
Review of quantum fields; quantization of the electromagnetic field; photodetection theory; direct, homodyne, and heterodyne detection; squeezed and photon-number state generation; application to optical communication and interferometers.

PHYSICS 428-1 Quantum Field Theory (1 Unit)
1. Lagrangian field theory, relativistic Lagrangians and wave equations, symmetries and conservation laws, canonical quantization, covariant perturbation theory, the S-Matrix, cross sections and lifetimes, and quantum electrodynamics. 2. Topics selected from: Path integral formulation of field theory, renormalization, Non-Abelian symmetries, the standard model of particle physics, C, P, and CP violation, the parton model and deep inelastic scattering, physics beyond the standard model, and nonperturbative methods.
Prerequisites: PHYSICS 412-1, PHYSICS 412-2, PHYSICS 412-3 or permission of instructor.

PHYSICS 428-2 Quantum Field Theory (1 Unit)
1. Lagrangian field theory, relativistic Lagrangians and wave equations, symmetries and conservation laws, canonical quantization, covariant perturbation theory, the S-Matrix, cross sections and lifetimes, and quantum electrodynamics. 2. Topics selected from: Path integral formulation of field theory, renormalization, Non-Abelian symmetries, the standard model of particle physics, C, P, and CP violation, the parton model and deep inelastic scattering, physics beyond the standard model, and nonperturbative methods.
Prerequisites: PHYSICS 412-1, PHYSICS 412-2, PHYSICS 412-3 or permission of instructor.

PHYSICS 428-3 Relativistic Quantum Field Theory (1 Unit)
1. Lagrangian field theory, relativistic Lagrangians and wave equations, symmetries and conservation laws, canonical quantization, covariant perturbation theory, the S-Matrix, cross sections and lifetimes, and quantum electrodynamics. 2. Topics selected from: Path integral formulation of field theory, renormalization, Non-Abelian symmetries, the standard model of particle physics, C, P, and CP violation, the parton model and deep inelastic scattering, physics beyond the standard model, and nonperturbative methods.
Prerequisites: PHYSICS 412-1, PHYSICS 412-2, PHYSICS 412-3 or permission of instructor.

PHYSICS 430-0 Nonlinear Dynamics & Chaos (1 Unit)
PHYSICS 431-0 Physics of Continuous Media (1 Unit)
Prerequisite: PHYSICS 411-0 or permission of instructor.

PHYSICS 432-1 Many-Body Theory (1 Unit)
Correlation, response, and Green's functions for many-particle systems; Feynman perturbation theory, Dyson's equation, symmetry and conservation laws, Fermi liquids, quasiparticles, Landau's transport equation, electron-ion plasma, electron-phonon interaction, Kondo effect, BSC theory, Gorkov's equations; thermodynamic and magnetic properties of superconductors; transport equations and electromagnetic response of superconductors.

PHYSICS 432-2 Many-Body Theory (1 Unit)
Correlation, response, and Green's functions for many-particle systems; Feynman perturbation theory, Dyson's equation, symmetry and conservation laws, Fermi liquids, quasiparticles, Landau's transport equation, electron-ion plasma, electron-phonon interaction, Kondo effect, BSC theory, Gorkov's equations; thermodynamic and magnetic properties of superconductors; transport equations and electromagnetic response of superconductors.

PHYSICS 434-0 Quantum Fluids, Solids, and Gases (1 Unit)
Bose-Einstein condensation, hydrodynamic and collisionless sound, superfluidity in Bose systems, broken symmetry and BCS pairing, excitations and particle-hole coherence, and superfluid 4He and 3He in films and channels.

PHYSICS 435-0 Soft Matter Physics (1 Unit)
Physical principles and techniques used in the study of molecular materials. Liquid crystals; polymers; floating monolayers; membranes; structured interfaces; self-assembly; complex and structured fluids; gels, colloids, and emulsions; DNA.

PHYSICS 436-0 Mesoscopic and Nanometer Scale Physics (1 Unit)
Selected topics related to quantum effects in mesoscopic systems. For example: quantum interference in disordered conductors, transport in semiconductor quantum dots, mesoscopic superconductors, and spin-polarized transport.

PHYSICS 440-0 Advanced Topics in Nuclear Physics (1 Unit)
Specialized lectures on current research topics.

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.

PHYSICS 442-0 Advanced Topics in Particle Physics (1 Unit)
Specialized lectures on current research topics in high-energy particle physics.

PHYSICS 445-1 General Relativity (1 Unit)
Review of special relativity and Newtonian gravity; Gravity as geometry of curved spacetime; Geodesics and conservation laws; Schwarzschild geometry; Gravitational collapse and black holes; Rotating black holes
and the Kerr geometry; Linearized gravity and gravitational waves;
Cosmological models for the expanding Universe.

**PHYSICS 445-2 General Relativity (1 Unit)**
First quarter: Review of special relativity and Newtonian gravity;
Gravity as geometry of curved spacetime; Geodesics and conservation
laws; Schwarzschild geometry; Tests of GR and the PPN formalism;
Gravitational collapse and black holes; Rotating black holes and the
Kerr geometry; Linearized gravity and gravitational waves; Cosmological
models for the expanding Universe. Second quarter: Differential geometry,
tensors, covariant derivatives; Riemann curvature and the field equation
in vacuum; Energy-momentum tensor, the Einstein equation; Perturbation
theory, gauge transformations; Emission of gravitational radiation;
More advanced applications, as time permits, such as: relativistic stars,
TOV equation and the Chandrasekhar limit, relativistic hydrodynamics;
ADM formalism and numerical relativity; quantum mechanics in curved
spacetime, inflationary cosmology.

**PHYSICS 450-0 Advanced Topics in Condensed Matter (1 Unit)**
Specialized lectures on current research topics.

**PHYSICS 460-0 Advanced Topics in Statistical Physics (1 Unit)**
Specialized lectures on current research topics.

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

**PHYSICS 470-0 Introduction to Biological Physics: From Molecules to
Cells (IBiS 410) (1 Unit)**
Quantitative physics-based approach to molecular and cell biology,
focused on developing an understanding of connections between
biomolecule structure and dynamics, and behavior of cells. The course
will also include review of topics from statistics of random variables and
statistical data analysis relevant to biology and biophysics.

**PHYSICS 480-0 Advanced Topics in Atomic, Molecular, and Optical
Physics (1 Unit)**
Specialized lectures on current research topics in atomic, molecular, and
optical physics.

**PHYSICS 499-0 Independent Study (1-3 Units)**
SEE DEPT FOR SECTION AND PERMISSION NUMBERS May be repeated
for credit. Permission of instructor and department required.

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

**PHYSICS 590-0 Research (1-3 Units)**
SEE DEPT FOR SECTION AND PERMISSION NUMBERS Independent
investigation of selected problems pertaining to thesis or dissertation.
May be repeated for credit.