PHYSICS

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.

Additional resources:

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

Degrees Offered

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

Physics: MS

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

- Demonstrate competency in all the required core course in first year Ph.D. Physics program.
- Master a breadth of core physics concepts.
- Utilize computer science in their research and coursework.
- Articulate research in written and oral form.
- Identify disciplinary subfields and evaluate subfield presentations.

Physics: PHD

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

- Develop classroom activities for a specific discussion section.
- Effectively communicate scientific research background, accomplishments, and new proposals.
- Carry out original research.
- Master a breadth of core and specialized physics concepts.
- Become conversant with modern research developments.

Physics Courses

PHYSICS 390-0 Topics in Physics (1 Unit)
This course will explore a specialized or current topic of research in a field of physics. Although the topic can change, it is expected that independent of the content, this is an advanced physics course that builds on core physics knowledge. Prerequisites vary by offering. It would generally require knowledge of at least one core physics course (Physics 330, 332, 333, 339) or the equivalent mathematics or permission from the instructor.

PHYSICS 405-0 Inclusive pedagogy, research foundations, curriculum and instruction in STEM (1 Unit)
Throughout this course, participants engage in reflection and discussions around topics of equity and inclusion in learning environments in different contexts. Identity, power, positionality and privilege informed by core principles seek to advance participants' awareness, self-efficacy, and ability to create inclusive STEM learning environments for their students. Key activities include embodied case studies and an inclusivity framework portfolio.

PHYSICS 410-0 Advancing Equity to Overcome the Exclusive Social Constructs in STEM (0.5 Unit)
Throughout history the most recognized scholars in STEM have been largely white and Asian males, excluding minoritized groups. This is reproduced today by sociological and structural policies and processes. We will explore this history and examine current efforts to create more inclusive science and engineering environments.

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 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 414-2 Electrodynamics (1 Unit)
A continuation of the graduate course in electrodynamics. Electromagnetic waves, optics, propagation of laser beams, diffraction and interference phenomena. Electromagnetic fields in and around dielectric and magnetic materials. Propagation of electromagnetic waves in different dielectric and metallic media. Radiation and scattering, including relativistic radiation.

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 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.

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PHYSICS 424-1 Particle Physics (1 Unit)
First Quarter: Overview of modern particle physics and experimental techniques, the quark model, particle production, quantum chromodynamics, quark density functions. Weak interactions including W and Z properties, charged and neutral currents, CP violations, neutrinos, and heavy quarks.

PHYSICS 424-2 Particle Physics (1 Unit)
Second Quarter: Overview of the Standard Model of particle physics. Deep-inelastic lepton scattering, neutrino oscillations, and collider physics. The experimental side of particle physics will be emphasized. Focus will be mainly on collider physics at the Tevatron and the upcoming Large Hadron Collider.
Prerequisite: PHYSICS 412-1 or consent of instructor.

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. 2,3. 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. 2,3. 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. 2,3. 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)
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 431-0 Physics of Continuous Media (1 Unit)
Fluids: Navier-Stokes equations, diffusion. Solids: kinematics, stress and strain tensors, and finite elasticity. Complex fluids: colloids, gels, and liquid crystals.
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 studyof 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)
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.

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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.