

# PHYS - PHYSICS

---

## PHYS401 Quantum Physics I (4 Credits)

The first of a two-semester survey of quantum mechanics, employing the formalism of Dirac notation, linear operators, and Hilbert spaces. Quantum state preparation and measurement, the Schrodinger equation in both its matrix and wave descriptions, and applications to systems such as the harmonic oscillator and the hydrogen atom.

**Prerequisite:** PHYS265 and PHYS371; and 1 course from (PHYS313, PHYS373, or MATH462).

**Additional Information:** Intended primarily for Physics and Astronomy majors.

## PHYS402 Quantum Physics II (3 Credits)

Applications of quantum mechanics to atomic, molecular, and solid state systems. Addition of angular momenta, multiparticle states, perturbation theory and other approximation techniques, scattering, and symmetries.

**Prerequisite:** PHYS401.

## PHYS404 Introduction to Statistical Thermodynamics (3 Credits)

Introduction to basic concepts in thermodynamics and statistical mechanics.

**Prerequisite:** PHYS371 or PHYS420.

## PHYS405 Advanced Experiments (3 Credits)

Advanced laboratory techniques. Selected experiments from many fields of modern physics. Emphasis on self-study of the phenomena, data analysis, and presentation in report form.

**Prerequisite:** PHYS375.

**Restriction:** Must be in a major within CMNS-Physics department.

## PHYS406 Experimental Research Development (3 Credits)

Part I of a two-semester, independent, experimental research project supervised by a faculty mentor. The student participates significantly in experimental design, set-up, and collection and analysis of real, physical data, including the evaluation of experimental uncertainties. The student maintains a lab notebook and completes an end-of-semester progress report.

**Prerequisite:** PHYS375.

**Restriction:** Permission of CMNS-Physics department.

**Additional Information:** The student is expected to work on the project for approximately 9 hours per week in a standard semester or a total of 135 hours in a non-standard semester. PHYS406 may not be used to satisfy an advanced physics elective.

## PHYS407 Undergraduate Experimental Research (3 Credits)

Students develop and complete an independent, experimental research project with a professor in the Physics Department. The project should be a continuation of work done in PHYS406. To obtain permission, students must submit a proposal describing the experimental work to be completed and this proposal must be approved by their faculty mentor, the associate chair for undergraduate education and the chair of the laboratory committee. Students must maintain a lab notebook, give an oral presentation and complete a written report on their research that includes data and error analysis.

**Prerequisite:** PHYS406; and permission of CMNS-Physics department.

**Restriction:** Must be in a major within CMNS-Physics department; and senior standing.

## PHYS410 Classical Mechanics (3 Credits)

Classical mechanics at a more advanced level, including its Newtonian, Lagrangian, and Hamiltonian formulations. Conservative and non-conservative forces; the calculus of variations; central force motion; non-inertial frames of reference; rigid body rotations; and selected advanced topics.

**Prerequisite:** PHYS265 and PHYS273; and (MATH243 or MATH246).

## PHYS411 Intermediate Electricity and Magnetism (4 Credits)

Foundations of electromagnetic theory, with extensive applications of the methods. Thorough treatment of wave properties of solutions of Maxwell's equations.

**Prerequisite:** PHYS313 or PHYS373.

## PHYS412 Intermediate Electricity and Magnetism I (4 Credits)

The first semester of a two semester course with emphasis on electrostatics and magnetostatics, boundary value problems, fields in matter, electrodynamics, and Maxwell's equations.

**Prerequisite:** PHYS373.

## PHYS413 Electricity and Magnetism II (3 Credits)

The second semester of a two semester course with emphasis on electromagnetic waves, potentials and gauge invariance, and relativistic electrodynamics

**Prerequisite:** PHYS313 or PHYS412.

**Credit Only Granted for:** PHYS411 or PHYS413.

## PHYS420 Principles of Modern Physics (3 Credits)

A survey of atomic and nuclear phenomena and the main trends in modern physics. Appropriate for students in engineering and other physical sciences.

**Prerequisite:** MATH246. And PHYS271 and PHYS270; or PHYS273.

**Credit Only Granted for:** PHYS371 or PHYS420.

## PHYS428 Physics Capstone Research (2-4 Credits)

Individual, focused research under the guidance of a faculty member. Discussion, presentations and, if appropriate, research group projects involved. Student must submit final research paper for completion of course. Paper may also serve as thesis required for High Honors in Physics. Not intended as a general "reading course" (see PHYS499).

**Restriction:** Must be in a major within CMNS-Physics department; and senior standing or higher; and permission of instructor.

**Repeatable to:** 4 credits.

## PHYS429 Atomic and Nuclear Physics Laboratory (3 Credits)

Classical experiments in atomic physics and more sophisticated experiments in current techniques in nuclear physics.

**Prerequisite:** PHYS405.

## PHYS431 Introduction to Solid State Physics (3 Credits)

Classes of materials; introduction to basic ideal and real materials' behavior including mechanical, electrical, thermal, magnetic and optical responses of materials; importance of microstructure in behavior. One application of each property will be discussed in detail.

**Prerequisite:** PHYS271, PHYS270, and MATH241.

**Cross-listed with:** ENMA460.

**Restriction:** Junior standing or higher; and must be in the Engineering: Materials Science program or Physics program.

**Credit Only Granted for:** ENMA460 or PHYS431.

**Additional Information:** Materials Engineering students take ENMA460 and Physics students take PHYS431.

**PHYS441 Topics in Nuclear and Particle Physics (3 Credits)**

A survey of concepts in particle and nuclear physics, with a topical emphasis on the impact of the Weak Interaction and the discovery of Parity Violation.

**Prerequisite:** PHYS401 or PHYS402.

**Corequisite:** PHYS402.

**PHYS444 Computing Beyond the Standard Model of Particle Physics (3 Credits)**

An exploration of the computing languages and techniques used to analyze large data sets in Large Hadron Collider physics with some discussion of applications in unrelated fields.

**Prerequisite:** PHYS371 and PHYS373; or permission of instructor.

**PHYS456 Making Physics Experiments (3 Credits)**

Laboratory course emphasizing practical skills used for making Physics experiments within the broader context of the maker movement and the maker culture. Design, fabrication, hands-on skills, repair, and safety. Practical skills not otherwise covered in traditional coursework (e.g.: carpentry, electronics disassembly/assembly, soldering, etc.).

**Prerequisite:** PHYS276; or permission of instructor.

**Restriction:** Permission of Physics Department.

**Credit Only Granted for:** PHYS499X or PHYS456.

**Formerly:** PHYS499X.

**PHYS457 Introduction to Quantum Computing (3 Credits)**

An introduction to the concept of a quantum computer, including algorithms that outperform classical computation and methods for performing quantum computation reliably in the presence of noise. As this is a multidisciplinary subject, the course will cover basic concepts in theoretical computer science and physics in addition to introducing core quantum computing topics. No previous background in quantum mechanics is required.

**Prerequisite:** 1 course with a minimum grade of C- from (ENEE290, MATH240, MATH341, MATH461, MATH243); and 1 course with a minimum grade of C- from (CMSC351, PHYS313).

**Cross-listed with:** CMSC457.

**Credit Only Granted for:** CMSC457 or PHYS457.

**Additional Information:** Only Physics students may use MATH243 to satisfy the Linear Algebra prerequisite for CMSC/PHYS457.

**PHYS467 Introduction to Quantum Technology (3 Credits)**

Investigates the basic concepts/building blocks of quantum computers, quantum key distribution, quantum networks, and quantum sensors. Examines what is needed to form a working qubit and different hardware platforms that implement them (for example, trapped ions, superconducting microwave circuits, color centers, and neutral atoms.) Conceptual and computational familiarity with complex numbers, vector spaces, bases, matrices, eigenvectors, and eigenvalues will be assumed, as well as quantum states/wave functions, and quantum measurement. Familiarity with spin-1/2 systems, and Pauli matrices is highly recommended.

**Prerequisite:** MATH141 and MATH240 or equivalent; and one of the following: PHYS360, PHYS401, PHYS457, CMSC457, or ENEE491; or permission of instructor.

**Cross-listed with:** ENEE492.

**Credit Only Granted for:** PHYS467 or ENEE492.

**PHYS474 Computational Physics (3 Credits)**

Introduction to computational physics. Overview of some of the most widely used methods of computational physics and computational methods, including data analysis and statistical methods, visualization, numerical solutions of ordinary and partial differential equations (classical equations of motion, Poisson's equation, time independent and time dependent Schrodinger equations) and Monte Carlo simulations. In addition to giving the students a basic working knowledge of these particular techniques, the goal is to make them proficient in scientific computing and programming in general, so that they will be prepared to tackle other computational and data analysis problems that they may encounter in the future. This course will use the programming language Python.

**Prerequisite:** PHYS373; and (PHYS165, CMSC106, or CMSC131).

**Recommended:** PHYS401 (strongly recommended).

**Additional Information:** Students will need a laptop for this course to run specific software; however, arrangements will be made for those who need them. Students will need to load the Python 3 language on your computer, which will be done in the first week of class. The class will use the "Anaconda" environment/distribution, which is available for Mac/Windows/Linux. Contact the department for more information.

**PHYS476 Introduction to Applied Machine Learning (3 Credits)**

Introduces machine learning techniques that are becoming pertinent in the technology industry. Focus on hands-on work using popular high-level libraries. Students are expected to have a background in functional programming, linear algebra, calculus, and mathematical modeling.

**Prerequisite:** PHYS165, PHYS274, and PHYS276; or interested students with backgrounds in functional programming, linear algebra and statistics, should contact the instructors to request permission.

**PHYS485 Electronic Circuits (3 Credits)**

Theory and application to experimental physics of modern semiconductor analog and digital circuits. Emphasis on understanding passive and active elements in practical circuits. Topics span the range from simple transistor circuits to microcomputers.

**Prerequisite:** PHYS272 and PHYS276.

**Restriction:** Must be in a major within CMNS-Physics department.

**PHYS487 Computerized Instrumentation (3 Credits)**

Concentration on computer interfaces to measurement devices. Includes a review of basic electronic circuits and measurement devices. Extensive work with arduinos, making use of a variety of measurement probes. Includes introduction to the C++ programming language, the Segger development environment, and real-time operating systems (RTOS) used in advanced physics experiments.

**Prerequisite:** PHYS276 or Permission of Instructor.

**Restriction:** Departmental Permission.

**PHYS499 Special Problems in Physics (1-16 Credits)**

Research or special study. Credit according to work done.

**PHYS601 Theoretical Dynamics (3 Credits)**

Lagrangian and Hamiltonian mechanics, two-body central force problem, rigid body motion, small oscillations, continuous systems.

**Prerequisite:** PHYS410; or students who have taken courses with comparable content may contact the department.

**PHYS603 Methods of Statistical Physics (3 Credits)**

Foundations and applications of thermodynamics and statistical mechanics.

**Credit Only Granted for:** PHYS602 or PHYS603.

**PHYS604 Methods of Mathematical Physics (3 Credits)**

Ordinary and partial differential equations of physics, boundary value problems, Fourier series, Green's functions, complex variables and contour integration.

**Prerequisite:** Must have completed coursework in advanced calculus; and (PHYS411 and PHYS410). Or students who have taken courses with comparable content may contact the department.

**PHYS606 Electrodynamics (4 Credits)**

Classical electromagnetic theory, electro- and magnetostatics, Maxwell equations, waves and radiation, special relativity.

**Prerequisite:** PHYS604; or students who have taken courses with comparable content may contact the department.

**PHYS610 Mathematical Methods and Their Applications in Classical Mechanics and Electrodynamics I (4 Credits)**

First course of a two-semester graduate level sequence on classical mechanics, electrodynamics and relativity and the mathematics that underlie these subjects. Mathematical methods will generally be introduced in the context of relevant physical problems.

**Prerequisite:** Must have an outstanding undergraduate background in physics.

**Restriction:** Permission of CMNS-Physics Department.

**PHYS611 Mathematical Methods and Their Applications in Classical Mechanics and Electrodynamics II (4 Credits)**

Second course of a two-semester graduate level sequence on classical mechanics, electrodynamics and relativity and the mathematics that underlie these subjects. Mathematical methods will generally be introduced in the context of relevant physical problems.

**Prerequisite:** PHYS610 or permission of instructor.

**Restriction:** Permission by Department.

**PHYS612 Quantum and Statistical Physics I (4 Credits)**

First course of a two-semester graduate level sequence on topics in quantum mechanics and statistical mechanics.

**Prerequisite:** Must have an outstanding undergraduate background in physics.

**Restriction:** Permission of CMNS-Physics Department.

**PHYS613 Quantum and Statistical Physics II (4 Credits)**

Second course of a two-semester graduate level sequence on topics in quantum mechanics and statistical mechanics.

**Prerequisite:** PHYS612; or permission of instructor.

**Restriction:** Permission of the Physics Department.

**PHYS622 Introduction to Quantum Mechanics I (4 Credits)**

First and second semesters. A study of the Schrodinger equation, matrix formulations of quantum mechanics, approximation methods, scattering theory, etc. Applications to solid state, atomic, and nuclear physics.

**Prerequisite:** Must have an outstanding undergraduate background in physics.

**PHYS623 Introduction to Quantum Mechanics II (3 Credits)**

First and second semesters. A study of the Schrodinger equation, matrix formulations of quantum mechanics, approximation methods, scattering theory etc., and applications to solid state, atomic, and nuclear physics. Continuation of PHYS 622.

**Prerequisite:** Must have an outstanding undergraduate background in physics.

**PHYS624 Introduction to Quantum Field Theory (3 Credits)**

Merging relativity and quantum mechanics using quantum fields, scalar field theory and canonical quantization, continuous and discrete symmetries, perturbation theory and scattering amplitudes, renormalized perturbation theory, Lorentz-group representations and fermionic field theories, massive and massless vector field theories and gauge invariance, quantum electrodynamics.

**Prerequisite:** PHYS613 or PHYS623.

**PHYS625 Quantum Many-Body Theory I (3 Credits)**

Non-relativistic second quantization, path integrals and functional field integrals, perturbation theory with Feynman diagrams, interacting electron gas.

**Prerequisite:** PHYS612 and PHYS613.

**PHYS626 Quantum Many-Body Theory II (3 Credits)**

Continuation of PHYS625. Functional-integral formulation of quantum field theory. Phase transitions and broken symmetry. Magnetism, superconductivity, and other applications. The renormalization group.

**Prerequisite:** PHYS612, PHYS613, and PHYS625.

**PHYS662 Intersections of Technology and Policy: Modernizing the Energy System (3 Credits)**

A broad, practical introduction to the issues and assessment approaches used to evaluate technical innovation in the Energy System. Introduction to the use of Sankey Diagrams, Life Cycle Analysis, Techno-economic analysis, and Equilibrium Economic Analysis, as well as policy factors such as Energy Efficiency Standards, Vehicle Fuel Economy, Feed-in-tariffs and environmental regulations.

**Restriction:** Must be a graduate student in the Natural Sciences, Engineering, Public Policy, or Economics; or must be a senior in the above disciplines with a minimum cumulative GPA of 3.0.

**Credit Only Granted for:** PHYS662 or PLCY699B.

**PHYS675 Introduction to Relativity, Gravitation and Cosmology (3 Credits)**

Review of special relativity, followed by a study of the equivalence principle, curved spacetimes, and Einstein's equations. Selected applications to the solar system, stellar structure, black holes, gravitational waves, and cosmology.

**Prerequisite:** PHYS606 and PHYS601.

**PHYS685 Research Electronics (3 Credits)**

An integrated lecture and laboratory course in electronics with equal emphasis on experimental methods and results and analysis using device models and up-to-date mathematical and numerical tools.

Experiments and analysis of circuits with passive and single active devices form the background for the study of operational amplifiers, digital integrated circuits and systems, and microcomputers. The general topics of impedance matching, frequency response, feedback, interfacing and the extraction of signal from noise are stressed.

**Prerequisite:** An outstanding undergraduate background in physics or permission of the instructor.

**Restriction:** Must not have completed PHYS485.

**Credit Only Granted for:** PHYS485 or PHYS685.

**PHYS703 Introduction to Nonequilibrium Statistical Physics (3 Credits)**

Analysis and microscopic modeling of systems away from thermal equilibrium. Linear response theory, ergodicity, Brownian motion, Monte Carlo modeling, thermal ratchets, far-from-equilibrium fluctuation relations. Introduction to the theoretical tools of nonequilibrium phenomena and their application to problems in physics, chemistry and biology.

**Prerequisite:** PHYS603 or CHEM687; or permission of instructor.

**Cross-listed with:** CHEM703, BIPH703, CHPH703.

**Credit Only Granted for:** BIPH703, CHEM703, CHPH703, or PHYS703.

**PHYS708 Seminar in Teaching College Physics (1 Credit)****PHYS709 Seminar in General Physics (1 Credit)****PHYS715 Chaotic Dynamics (3 Credits)**

Theory and applications of chaos in dynamical systems including such topics as strange attractors, Lyapanov exponents, quasiperiodicity, period doubling, intermittency, crises, fractal basin boundaries, chaotic scattering, KAM tori, and quantum chaos.

**Prerequisite:** PHYS601.

**PHYS718 Seminar in General Physics (1 Credit)****PHYS719 Seminar in General Physics (1 Credit)****PHYS720 Quantum Technology (3 Credits)**

Physical principles behind emerging quantum technologies, from quantum-limited sensors to quantum simulators, by applying quantum optics formalism. Examination of current and emerging platforms for quantum technologies, including neutral atom, ion trap, superconducting circuit, photonic, and spin-based approaches. Focus on hurdles for implementing quantum devices for new applications.

**Prerequisite:** A good grounding in electromagnetism and quantum mechanics is necessary; familiarity with density matrices and master equations will be helpful.

**PHYS721 Atomic and Optical Physics I (Survey) (3 Credits)**

A survey of topics involving the physics of atoms and their interaction with radiation, including atoms in external fields, lasers, atomic spectroscopy and atomic structure.

**Prerequisite:** PHYS623.

**PHYS728 Seminar in Atomic and Molecular Physics (1 Credit)****PHYS731 Solid State Physics: Survey (3 Credits)**

A variety of topics such as crystal structure, mechanical, thermal, electrical, and magnetic properties of solids, band structure, the Fermi surface, and superconductivity will be treated. Although the emphasis will be on the phenomena, the methods of quantum mechanics are freely employed in this description.

**PHYS732 Introduction to Solid State Physics II (3 Credits)**

Second semester of survey course in condensed matter physics including topics in semiconductors, surface physics, magnetism and superconductivity.

**Prerequisite:** PHYS731.

**PHYS738 Seminar in Experimental Solid State Physics (1 Credit)****PHYS739 Seminar in Theoretical Solid State Physics (1 Credit)****PHYS748 Seminar in Experimental Nuclear Physics (1 Credit)****PHYS749 Seminar in Theoretical Nuclear Physics (1 Credit)****PHYS752 Elementary Particle Physics II: Theory (3 Credits)**

Survey of elementary particles and their properties, quantum field theory, meson theory, weak interactions, possible extensions of elementary particle theory.

**Prerequisite:** PHYS751 and PHYS624.

**PHYS758 Seminar in Elementary Particles and Quantum Field Theory (1 Credit)****PHYS759 Seminar in Elementary Particles and Quantum Field Theory (1 Credit)****PHYS761 Plasma Physics I: Survey (3 Credits)**

A detailed study of plasma physics. The first semester treats particle orbit theory, magnetohydrodynamics, plasma waves, and transport phenomena.

**Prerequisite:** PHYS606 and PHYS604.

**PHYS762 Plasma Physics II (3 Credits)**

Continuation of PHYS 761. Vlasov theory, including waves, stability, and weak turbulence, kinetic equation theories of correlations and radiative processes.

**Prerequisite:** PHYS761.

**PHYS769 Seminar in Plasma Physics (1 Credit)****PHYS778 Seminar in Space and Cosmic Ray Physics (1 Credit)****PHYS779 Seminar in General Relativity (1 Credit)****PHYS780 Network Science Literature Survey Seminar (1 Credit)**

Identify and develop a research project in Network Science. Practice communicating scientific results and concepts to individuals in their own field and in other fields to which the research is applicable.

**Credit Only Granted for:** PHYS780 or PHYS798T.

**Formerly:** PHYS798T.

**PHYS781 Network Science Research-in-Progress Seminar (1 Credit)**

Practice communicating scientific results and concepts to a general scientific audience, based on the student's research-in-progress.

**Credit Only Granted for:** PHYS781 or PHYS798U.

**Formerly:** PHYS798U.

**PHYS782 Interdisciplinary Research and Communication Practicum for Data-Driven Science (3 Credits)**

Semester-long, individual research project under the direction of a faculty mentor. Students will concurrently use this project to develop and refine their communication skills of scientific concepts. Will address interdisciplinary communication with some discussion of data exploration, analysis, and visualization.

**Credit Only Granted for:** PHYS782 or PHYS798N.

**Formerly:** PHYS798N.

**PHYS798 Special Problems in Advanced Physics (1-3 Credits)**

Projects or special study in advanced physics.

**PHYS799 Master's Thesis Research (1-6 Credits)****PHYS808 Special Topics in General Physics (1-4 Credits)**

Credit according to work done.

**PHYS809 Special Topics in General Physics (1-4 Credits)**

Credit according to work done.

**PHYS818 Special Topics in General Physics (1-4 Credits)**

Credit according to work done.

**PHYS819 Special Topics in General Physics (1-4 Credits)**

Credit according to work done.

**PHYS828 Special Topics in Atomic and Molecular Physics (1-4 Credits)**

Credit according to work done.

**PHYS829 Special Topics in Quantum Mechanics and Quantum Electronics (1-4 Credits)**

Credit according to work done.

**PHYS830 Topics in Theoretical Condensed Matter Physics (3 Credits)**

A variety of current advanced topics in condensed matter theory will be treated in a tutorial format. Students should be familiar with concepts such as renormalization group theory, phase transitions, quantum information, and topological concepts.

**Restriction:** Permission of instructor.

**PHYS838 Special Topics in Experimental Solid State Physics (1-4 Credits)**

Credit according to work done.

**PHYS839 Special Topics in Theoretical Solid State Physics (1-4 Credits)**

Credit according to work done.

**PHYS849 Special Topics in Theoretical Nuclear Physics (1-4 Credits)**

Credit according to work done.

**PHYS851 Advanced Quantum Field Theory (3 Credits)**

Renormalized quantum electrodynamics, non-Abelian gauge theories, quantum chromodynamics and asymptotic freedom, electroweak theory and Higgs mechanism, path-integral formulation and non-perturbative approaches to quantum field theories.

**Prerequisite:** PHYS624.

**PHYS858 Special Topics in Elementary Particles and Quantum Field Theory (1-4 Credits)**

First semester.

**Prerequisite:** PHYS752 and PHYS851.

**PHYS859 Special Topics in Elementary Particles and Quantum Field Theory (1-4 Credits)**

Credit according to work done.

**PHYS869 Special Topics in Plasma Physics (1-4 Credits)**

Credit according to work done.

**PHYS878 Special Topics in Space and Cosmic Ray Physics (1-4 Credits)**

Credit according to work done.

**PHYS879 Special Topics in General Relativity (1-4 Credits)**

Credit according to work done.

**PHYS888 Special Topics in Applied Physics (2 Credits)****PHYS889 Special Topics in Interdisciplinary Problems (1-4 Credits)**

Credit according to work done.

**Restriction:** Permission of instructor.

**PHYS898 Pre-Candidacy Research (1-8 Credits)****PHYS899 Doctoral Dissertation Research (1-8 Credits)**