The Department of Physics offers work leading to degrees in Physics at both the master's and doctoral levels. Experimental and theoretical work leading to a graduate degree is available in the following general areas: atomic, molecular, and laser physics; biophysics; condensed matter and materials physics; high-energy particle physics; and high-energy nuclear physics.

**Admission and Degree Requirements**

- **MS in Physics**
- **PhD in Physics**

**PHYS 401. Electromagnetism I. 4 hours.**
Vector calculus; electrostatic and magnetostatic fields in vacuum; electrostatic boundary-value problems; electrodynamics; Maxwell's equations; electromagnetic waves in vacuum; reflection and transmission phenomena in linear media. Prerequisite(s): PHYS 215 and MATH 220; or approval of the department.

**PHYS 402. Electromagnetism II. 4 hours.**
Electrostatics, magnetostatics, and electromagnetic waves in matter; radiation; relativistic electrodynamics; special topics chosen by the instructor. Course Information: Prerequisite(s): PHYS 230 and PHYS 401; or approval of the department.

**PHYS 411. Quantum Mechanics I. 4 hours.**
Wave particle duality; wave functions; matrix representation; operators and observables; 1-D potentials; harmonic oscillator; eigenfunctions; time-independent perturbation theory; approximation methods; 3-D Schroedinger's equation. Course Information: Prerequisite(s): PHYS 215 and PHYS 240 and PHYS 245; or approval of the department. Recommended background: MATH 220.

**PHYS 412. Quantum Mechanics II. 4 hours.**
This is the second semester of a two-semester undergraduate level sequence on the concepts and methods of Quantum Mechanics and their applications. Course Information: Prerequisite(s): PHYS 411; or approval of the department.

**PHYS 421. Modern Physics: Atoms and Molecules. 4 hours.**
Hydrogenic atoms, electron spin, external fields, multi-electron atoms, diatomic molecules, line widths, photons, radiation from atoms and other electromagnetic processes, positrons, positronium, elastic electron scattering. Course Information: Prerequisite(s): Credit or concurrent registration in PHYS 411.

**PHYS 425. Modern Optics. 4 hours.**
Review of electromagnetic wave theory and introductory optics; advanced geometrical optics; Fourier transforms and optics; interference and diffraction; solar cells and LEDs; laser cavities and gain media; introduction to nonlinear and fiber optics. Course Information: Prerequisite(s): PHYS 240; or approval of the department. Class Schedule Information: To be properly registered, students must enroll in one Discussion, one Laboratory and one Lecture.

**PHYS 431. Modern Physics: Condensed Matter. 4 hours.**
Crystal structures; interatomic binding; lattice vibrations; thermal and magnetic properties; quantum statistical mechanics; free electron theory of metals; electronic band theory; semiconductors and insulators; superconductivity. Course Information: Prerequisite(s): PHYS 411 and PHYS 461; or consent of the instructor.

**PHYS 441. Theoretical Mechanics. 4 hours.**
Review of Newtonian mechanics, variational calculus, Lagrangian mechanics, central force problems, non-inertial frames, rigid body motion, coupled oscillators, non-linear mechanics, Hamiltonian mechanics, and numerical examples. Course Information: Prerequisite(s): PHYS 215 and Credit or concurrent registration in PHYS 245; or approval of the department.

**PHYS 450. Molecular Biophysics of the Cell. 4 hours.**
Introduction to force, time energies at nanometer scales; Boltzmann distribution; hydrodynamic drag; Brownian motions; DNA, RNA proteins; structure and function; sedimentation; chemical kinetics; general aspects of flexible polymers. Course Information: Same as BIOE 450. Prerequisite(s): PHYS 245 or the equivalent; or approval of the department.

**PHYS 451. Modern Physics: Nuclei and Elementary Particles. 4 hours.**
Accelerators, detectors, symmetries, conservation laws, leptons, weak interactions, electromagnet theory, strong interactions, hadrons, nuclear forces, systematics and reactions, nuclear models, nuclear astrophysics, quarks, quantum chromodynamics. Course Information: Prerequisite(s): PHYS 411.

**PHYS 461. Thermal and Statistical Physics. 4 hours.**
Thermal equilibrium (Zeroth Law); thermodynamic states (First Law); irreversibility; entropy (Second Law); thermodynamic potentials and properties; phase transitions; kinetic theory of gases; classical statistical mechanics. Course Information: Prerequisite(s): PHYS 245; or approval of the department.

**PHYS 469. The Learning and Teaching of Physics. 4 hours.**
Provides teacher candidates with the foundations and experiences necessary for teaching physics in secondary schools. For those currently teaching, it will also provide tools and background to improve their physics instruction. Course Information: 4 hours. Extensive computer use required. Prerequisite(s): PHYS 142; or PHYS 107 and PHYS 108; or approval of the department. Class Schedule Information: To be properly registered, students must enroll in one Lecture-Discussion and one Laboratory.
PHYS 470. Educational Practice with Seminar I. 6 hours.
The first half of a two-segment sequence of practice teaching, including seminar, to meet certification requirements for teaching in grades six through twelve. Course Information: Graduate credit only with approval of the department. Prerequisite(s): Good academic standing in a teacher education program, completion of 100 clock hours of pre-student-teaching field experiences, and approval of the department. Class Schedule Information: To be properly registered, students must enroll in one Lecture-Discussion and one Practice.

PHYS 471. Educational Practice with Seminar II. 6 hours.
The second half of a two-segment sequence of practice teaching, including seminar, to meet certification requirements for teaching in grades six through twelve. Course Information: Graduate credit only with approval of the department. Prerequisite(s): Good academic standing in a teacher education program, completion of 100 clock hours of pre-student-teaching field experiences, credit or concurrent registration in PHYS 470, and approval of the department. Class Schedule Information: To be properly registered, students must enroll in one Conference and one Practice.

PHYS 475. Learning and Teaching of Physical Sciences. 3 hours.
Provides teacher candidates with the foundation and experience necessary to teach physical sciences in secondary schools. Course Information: Same as CHEM 475. Prerequisite(s): Senior standing or above; or approval of the department. Recommended background: Knowledge of first-year college physics and chemistry. Class Schedule: To be properly registered students must enroll in one Lecture-Discussion and one Laboratory.

PHYS 480. Elements of Machining Scientific Equipment. 1 hour.
Elements of machining scientific equipment, including the use of machine shop tools and technical drawing of scientific apparatus. Course Information: Same as CHEM 480 and EAES 478. Satisfactory/Unsatisfactory grading only. Prerequisite(s): Graduate standing; and approval of the department.

PHYS 481. Modern Experimental Physics I. 4 hours.
Theory and experimental use of linear circuits, semiconductor devices, amplifiers, oscillators. Techniques and experiments in atomic, molecular and solid-state physics. Course Information: Prerequisite(s): PHYS 240; or approval of the department. Requires concurrent registration in PHYS 499 for students enrolled in the BA or BS in Physics programs. Class Schedule Information: To be properly registered, students must enroll in one Laboratory and one Lecture-Discussion.

PHYS 482. Modern Experimental Physics II. 4 hours.
Techniques and experiments in nuclear and particle physics. Gamma-gamma correlations, muon lifetime, Compton scattering, alpha particle scattering. Computer-based experimentation. Course Information: Prerequisite(s): PHYS 481; or approval of the department. Class Schedule Information: To be properly registered, students must enroll in one Laboratory and one Lecture-Discussion.

PHYS 491. Special Topics in Physics. 1-4 hours.
Selected topics of current interest in Physics. Course Information: May be repeated. Prerequisite(s): PHYS 215 and sophomore standing or above; or approval of the department.

PHYS 494. Special Topics in Physics Teaching. 2-4 hours.
Seminar on various topics related to the teaching of physics. Subjects are announced. Course Information: May be repeated. Students may register in more than one section per term. Supervised teaching practice included. Prerequisite(s): Graduate standing or approval of the department.

PHYS 499. Survey of Physics Problems. 1 hour.
Problem-solving techniques applied to the variety of undergraduate physics topics. Course Information: No graduation credit for graduate students. Grade of C or better required to graduate with an undergraduate degree in physics. Co-requisite(s): Concurrent registration in PHYS 481.

PHYS 501. Electrodynamics I. 4 hours.
Maxwell's equations, static and time dependent fields in material media and in vacuo. Boundary value problems, wave propagation. Classical theory of radiation. Course Information: Prerequisite(s): PHYS 402 or approval of the department.

PHYS 502. Electrodynamics II. 4 hours.
Special relativity in electrodynamics. Covariant form of Maxwell's equations. Lagrangian form of electrodynamics. Applications to modern physics problems. Course Information: Prerequisite(s): PHYS 501 or consent of the department.

PHYS 511. Quantum Mechanics I. 3 hours.
Lagrangian formulation of relativistic wave equations. Quantum electrodynamics; Feynman rules, trace theorems, lowest-order calculations for several processes, self-energy, renormalization, higher-order diagrams. Course Information: Prerequisite(s): PHYS 412 or approval of the department.

PHYS 512. Quantum Mechanics II. 4 hours.
Scattering theory, partial waves, Born approximation, density matrix, interaction of radiation with matter; Klein-Gordon and Dirac equations, free-particle solutions, antiparticles, relativistic hydrogen atom. Second quantization. Course Information: Prerequisite(s): PHYS 511 or approval of the department.

PHYS 513. Quantum Field Theory I. 3 hours.
Lagrangian formulation of relativistic wave equations. Quantum electrodynamics; Feynman rules, trace theorems, lowest-order calculations for several processes, self-energy, renormalization, higher-order diagrams. Course Information: Prerequisite(s): PHYS 512.

PHYS 514. Quantum Field Theory II. 3 hours.
Path integrals, gauge theories, Weinberg-Salam model, electroweak processes, quantum chromodynamics, non-perturbative methods, topological objects in field theories, instantons. Course Information: Prerequisite(s): PHYS 513.

PHYS 515. Methods in Mathematical Physics. 3 hours.
Applications of mathematical methods to physics problems, linear operators, orthogonal functions, Green's functions, ordinary and partial differential equations, Sturm-Liouville problem, Hilbert space, group theory. Course Information: Prerequisite(s): PHYS 215.

PHYS 521. Molecular Physics. 3 hours.
Rotational and vibrational energies of molecules, potential curves, electronic transitions, transition moments, intensity rules, thermodynamic properties. Applications. Course Information: Prerequisite(s): PHYS 411 and PHYS 421; or approval of the department.

PHYS 522. Laser Physics/Quantum Electronics. 3 hours.
Lasers and quantum electronics. Modern laser systems; coherence phenomena; applications of lasers. Course Information: Prerequisite(s): PHYS 521 or approval of the department.

PHYS 524. Group Theory in Physics. 3 hours.
Applications of group theory and symmetry principles to problems in elementary particle, solid state, atomic and molecular physics. Course Information: Prerequisite(s): PHYS 512 or approval of the department.
PHYS 525. Optics and Photonics. 2 hours.
Electromagnetic wave theory; advanced geometrical, nonlinear, fiber, and Fourier optics; Fourier transforms; interference; diffraction; solar cells; LEDs; laser cavities; gain media. More challenging problem sets, exams, labs than in Phys 425. Course Information: Corequisites: Requires concurrent registration in PHYS 425. To be properly registered, students must enroll in one Lecture, one Laboratory, and one Discussion.

PHYS 531. Solid State Physics I. 3 hours.
Crystal structure, reciprocal lattice, X-ray methods, crystal forces, phonons, heat capacity, thermal expansion. Classification of solids, band structure. Metals: free-electron model, band-structure effects, transport. Course Information: Prerequisite(s): PHYS 412 AND PHYS 461.

PHYS 532. Solid State Physics II. 3 hours.
Semiconductor physics, electron-electron and electron-phonon interactions, superconductivity, spin systems, diamagnetism, paramagnetism, ferromagnetism, and anti-ferromagnetism. Course Information: Prerequisite(s): PHYS 531.

PHYS 533. Theory of Solids: Magnetism and Superconductivity. 3 hours.
The main body problem; many-particle states; functional integrals; Green's functions; Feynman diagrams; perturbation expansions; tree diagrams. Course Information: Prerequisite(s): PHYS 512 and PHYS 532.

PHYS 534. Theory of Solids: Semiconductor Physics. 3 hours.
Spin systems; magnetism; equilibrium Green's functions; Landau theory of Fermi liquids; Hubbard model; Luttinger model, non-equilibrium Green's functions, Keldysh, Kadanoff-Baym approach. Course Information: Prerequisite(s): PHYS 512 and PHYS 532.

PHYS 540. Physics of Semiconductor Devices. 4 hours.
Electrons in periodic lattice; equilibrium carrier distribution; energy band diagrams in junctions, in homogeneous semiconductors; recombination and generation; non-equilibrium processes, radiation and electric fields; diodes. Course Information: Same as ECE 540. Prerequisite(s): ECE 346 or the equivalent.

PHYS 545. Introduction to General Relativity. 3 hours.
Principle of equivalence, the metric field and geodesics, tensor analysis and differential geometry, Einstein's equations and the action principle, gravitational fields and waves, black holes. Course Information: Prerequisite(s): PHYS 502 and PHYS 541 or approval of the department.

PHYS 551. Elementary Particle Physics I. 3 hours.
Phenomenology and theories of modern day particle physics. Classification of particles and their interactions. Survey of experimental techniques, accelerators and detectors. Course Information: Prerequisite(s): PHYS 512 or approval of the department.

PHYS 552. Elementary Particle Physics II. 3 hours.
Lagrangian formulation of electromagnetic, weak and strong interactions. Transition rates. Unification of electroweak and strong interactions. Gauge theories. Modern topics. Course Information: Prerequisite(s): PHYS 551 or approval of the department.

PHYS 561. Statistical Mechanics. 3 hours.
Density matrix. Information theory; Boltzmann-Gibbs distribution; the vector model; renormalization group theory; cellular automata. Course Information: Prerequisite(s): PHYS 461 or approval of the department.

PHYS 581. Advanced Experimental Physics. 2 hours.
Experimental techniques in atomic, molecular and solid-cular and solid-state physics. Course Information: Prerequisite(s): PHYS 431 or consent of the instructor.

PHYS 594. Special Topics in Modern Physics. 1-4 hours.
Lectures on topics of current interest. Subjects are announced in the previous semester. Course Information: May be repeated. Students may register in more than one section per term. Prerequisite(s): PHYS 512.

PHYS 595. Graduate Seminar. 1 hour.
Seminars in areas of research activity within the department covering recent contributions to the literature and research in progress. Presentations by students, faculty and scientists from other institutions. Course Information: Satisfactory/Unsatisfactory grading only. May be repeated to a maximum of 6 hours. Students may register in more than one section per term.

PHYS 596. Individual Study. 2-4 hours.
Special topics. Outside reading and a term paper are assigned by a special arrangement with the department and faculty. Course Information: Satisfactory/Unsatisfactory grading only. May be repeated. Students may register in more than one section per term. Prerequisite(s): Approval of the department.

PHYS 598. Master's Thesis Research. 0-16 hours.
Student may elect to do thesis research to fulfill partial requirement for master's degree. Course Information: Satisfactory/Unsatisfactory grading only. Prerequisite(s): Approval of the department.

PHYS 599. Thesis Research. 0-16 hours.
Ph.D. thesis research. Course Information: Satisfactory/Unsatisfactory grading only. May be repeated. Prerequisite(s): Approval of the department.