PHYS 411. Modern Physics: Nuclei and Elementary Particles. 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): PHYS 411 and PHYS 461; or consent of the instructor.

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): 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.
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 411 and PHYS 461; or consent of the instructor.

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 protein 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: Condensed Matter. 4 hours.
Accelerators, detectors, symmetries, conservation laws, leptons, weak interactions, electroweak theory, strong interactions, hadrons, nuclear forces, systematics and reactions, nuclear models, nuclear astrophysics, quarks, quantum chromodynamics. Course Information: Prerequisite(s): PHYS 411.

PHYS 451. Modern Physics: Nuclei and Elementary Particles. 4 hours.
Review of Newtonian mechanics, 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 411 and PHYS 461; or approval of the department.

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 461. The Learning and Teaching of Physics. 4 hours.
PHYS 461. Modern Physics: Condensed Matter. 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): PHYS 411 AND PHYS 461; OR CONSENT OF THE INSTRUCTOR.

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): PHYS 411 AND PHYS 461; OR CONSENT OF THE INSTRUCTOR.
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 Conference 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.
Linear operators, vector spaces. Schrödinger equation. Heisenberg
formalism. Multi/identical particle systems, approximation methods,
perturbation theory, symmetries and groups, conservation laws,
angular momentum, spin. Wigner-Eckart theorem. 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.
Laser physics; population inversion; quantum theoretical calculation;
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 556. Statistical Mechanics. 3 hours.
Density matrix. Information theory; Boltzmann-Gibbs distribution; the n-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.