PHYSICS

Graduate study and opportunities for basic research are offered in the areas of nuclear physics, theoretical physics, condensed matter physics, elementary particle physics, plasma physics, atomic and molecular physics, optical science and engineering, laser physics, fundamental measurements, liquid crystal science and technology, biophysics, and physics education research.

Doctoral programs in chemical physics and geophysics are offered jointly with the Department of Chemistry and with the other departments that participate in the interdepartmental geophysics program.

Course code for this program is PHYS.

Master's Degree
- Physics - Master of Science (MS) (catalog.colorado.edu/graduate/colleges-schools/arts-sciences/programs-study/physics/physics-master-science-ms)

Doctoral Degree
- Physics - Doctor of Philosophy (PhD) (catalog.colorado.edu/graduate/colleges-schools/arts-sciences/programs-study/physics/physics-doctor-philosophy-phd)

Faculty
While many faculty teach both undergraduate and graduate students, some instruct students at the undergraduate level only. For more information, contact the faculty member's home department.

Anderson, Dana Z (https://experts.colorado.edu/display/fisid_102371)
Professor; PhD, University of Arizona

Ashby, Neil
Professor Emeritus

Baker, Daniel N (https://experts.colorado.edu/display/fisid_103264)
Distinguished Professor; PhD, University of Iowa

Bartlett, David
Professor Emeritus

Beale, Paul D (https://experts.colorado.edu/display/fisid_101602)
Professor; PhD, Cornell University

Becker, Andreas (https://experts.colorado.edu/display/fisid_146675)
Associate Professor; Dr habil, Universite Laval (Canada)

Betterton, Meredith D (https://experts.colorado.edu/display/fisid_125396)
Associate Professor; PhD, Harvard University

Bolton, Daniel Ryan (https://experts.colorado.edu/display/fisid_155168)
Instructor; PhD, University of Washington

Calkins, Michael Andrew (https://experts.colorado.edu/display/fisid_149720)
Assistant Professor; PhD, University of California-Los Angeles

Cary, John R (https://experts.colorado.edu/display/fisid_105901)
Professor; PhD, University of California-Berkeley

Chasteen, Stephanie Viola (https://experts.colorado.edu/display/fisid_145183)
Lecturer

Clark, Noel A (https://experts.colorado.edu/display/fisid_101947)
Professor; PhD, Massachusetts Institute of Technology

Cooper, John
Professor Emeritus

Cumalat, John P (https://experts.colorado.edu/display/fisid_105582)
Professor; PhD, University of California-Santa Barbara

Cundiff, Steven (https://experts.colorado.edu/display/fisid_112280)
Lecturer

De Alwis, Senarath P (https://experts.colorado.edu/display/fisid_103029)
Professor; PhD, University of Cambridge (England)

Degrand, Thomas A (https://experts.colorado.edu/display/fisid_102740)
Professor; PhD, Massachusetts Institute of Technology

Dessau, Daniel S (https://experts.colorado.edu/display/fisid_107532)
Professor; PhD, Stanford University

DeWolfe, Oliver M (https://experts.colorado.edu/display/fisid_142992)
Associate Professor; PhD, Massachusetts Institute of Technology

Dincao, Jose Paulo (https://experts.colorado.edu/display/fisid_143731)
Asst Research Professor; PhD, Univ of Sao Paulo (Brazil)

Dreitlein, Joseph
Professor Emeritus

Dubson, Michael A (https://experts.colorado.edu/display/fisid_102266)
Senior Instructor; PhD, Cornell University

Faller, James E (https://experts.colorado.edu/display/fisid_102047)
Professor Adjunct

Finkelstein, Noah D (https://experts.colorado.edu/display/fisid_129919)
Professor; PhD, Princeton University

Ford, William T.
Professor Emeritus

Franklin, Allan D.
Professor Emeritus

Glaser, Matthew A (https://experts.colorado.edu/display/fisid_105271)
Professor Attendant Rank

Glenn, Jason (https://experts.colorado.edu/display/fisid_115556)
Professor; PhD, University of Arizona

Goldman, Martin V (https://experts.colorado.edu/display/fisid_100567)
Professor; PhD, Harvard University

Gopinath, Juliet T (https://experts.colorado.edu/display/fisid_147075)
Assistant Professor; PhD, Massachusetts Institute of Technology

Gurarie, Victor Vladimir (https://experts.colorado.edu/display/fisid_129918)
Professor; PhD, Princeton University

Halverson, Nils W (https://experts.colorado.edu/display/fisid_134252)
Associate Professor; PhD, California Institute of Technology
Hamilton, Andrew J S (https://experts.colorado.edu/display/fisid_101517)
Professor; PhD, University of Virginia

Hasenfratz, Anna (https://experts.colorado.edu/display/fisid_102393)
Professor; PhD, Lorand Eotvos University, Budapest (Hungary)

Hermann, Allen M.
Professor Emeritus

Hermele, Michael Aaron (https://experts.colorado.edu/display/fisid_143370)
Associate Professor; PhD, University of California-Santa Barbara

Holland, Murray John (https://experts.colorado.edu/display/fisid_105126)
Professor; PhD, Oxford Univ (England)

Horanyi, Mihaly (https://experts.colorado.edu/display/fisid_102420)
Professor; PhD, Lorand Eotvos University, Budapest (Hungary)

Hough, Loren Evan (https://experts.colorado.edu/display/fisid_144904)
Assistant Professor; PhD, University of Colorado Boulder

Jaron-Becker, Agnieszka Anna (https://experts.colorado.edu/display/fisid_146689)
Assoc Research Professor; PhD, Univ of Warsaw (Poland)

Kapteyn, Henry C (https://experts.colorado.edu/display/fisid_115334)
Professor; PhD, University of California-Berkeley

Kempf, Sascha (https://experts.colorado.edu/display/fisid_149628)
Assistant Professor; Dr habil, Tech Univ of Braunschweig (Germany)

Kinney, Edward R (https://experts.colorado.edu/display/fisid_101717)
Professor; PhD, Massachusetts Institute of Technology

Kunz, P. Dale
Professor Emeritus

Lee, Minhyea (https://experts.colorado.edu/display/fisid_145209)
Assistant Professor; PhD, University of Chicago

Lewandowski, Heather Jean (https://experts.colorado.edu/display/fisid_111815)
Associate Professor; PhD, University of Colorado Boulder

MacLennan, Joseph E (https://experts.colorado.edu/display/fisid_104854)
Professor Attendant Rank

Mahanthappa, K. T.
Professor Emeritus; PhD, Harvard University; PhD, Harvard University

Marino, Alysia Diane (https://experts.colorado.edu/display/fisid_146427)
Associate Professor; PhD, University of California-Berkeley

Miller, Stanley
Professor Emeritus

Munsat, Tobin Leo (https://experts.colorado.edu/display/fisid_134251)
Associate Professor; PhD, Princeton University

Murnane, Margaret (https://experts.colorado.edu/display/fisid_115333)
Distinguished Professor; PhD, University of California-Berkeley

Nagle, James L (https://experts.colorado.edu/display/fisid_126784)
Professor; PhD, Yale University

Nandkishore, Rahul Mahajan (https://experts.colorado.edu/display/fisid_156417)
Assistant Professor; PhD, Massachusetts Institute of Technology

Nauenberg, Uriel
Professor Emeritus

Neil, Ethan (https://experts.colorado.edu/display/fisid_153411)
Assistant Professor; PhD, Yale University

Nesbitt, David (https://experts.colorado.edu/display/fisid_100333)
Professor Adjunct; PhD, University of Colorado

O'sullivan, William J.
Professor Emeritus

Parker, Scott E (https://experts.colorado.edu/display/fisid_109685)
Professor; PhD, University of California-Berkeley

Perkins, Katherine K. (https://experts.colorado.edu/display/fisid_124217)
Assoc Professor Attendant Rank

Peterson, R. Jerome
Professor Emeritus; PhD, University of Washington; PhD, University of Washington

Phillipson, Paul E.
Professor Emeritus

Pollock, Steven J (https://experts.colorado.edu/display/fisid_101392)
Professor; PhD, Stanford University

Price, John C (https://experts.colorado.edu/display/fisid_101129)
Professor; PhD, Stanford University

Radzihovsky, Leo (https://experts.colorado.edu/display/fisid_107484)
Professor; PhD, Harvard University

Rankin, Patricia (https://experts.colorado.edu/display/fisid_105939)
Professor; PhD, University of London (England)

Raschke, Markus B (https://experts.colorado.edu/display/fisid_148716)
Professor; PhD, Tech Univ of Munich (Germany)

Regal, Cindy Anne (https://experts.colorado.edu/display/fisid_144184)
Associate Professor; PhD, University of Colorado Boulder

Reznik, Dmitry (https://experts.colorado.edu/display/fisid_147659)
Associate Professor; PhD, University of Illinois at Urbana-Champaign

Ristinen, Robert
Professor Emeritus

Ritzwoller, Michael H (https://experts.colorado.edu/display/fisid_102264)
Professor; PhD, University of California-San Diego

Robertson, Scott H.
Professor Emeritus

Rogers, Charles (https://experts.colorado.edu/display/fisid_101331)
Professor; PhD, Cornell University

Romatschke, Paul (https://experts.colorado.edu/display/fisid_149870)
Assistant Professor; PhD, Technical Univ of Vienna (Austria)
Schibli, Thomas Richard (https://experts.colorado.edu/display/fisid_143464)
Associate Professor; PhD, Univ of Karlsruhe (Germany)

Shaheen, Sean Eric (https://experts.colorado.edu/display/fisid_153664)
Associate Professor; PhD, University of Arizona

Shepard, James R.
Professor Emeritus

Smalyukh, Ivan I (https://experts.colorado.edu/display/fisid_144757)
Associate Professor; PhD, Kent State University

Smythe, Rodman
Professor Emeritus

Stenson, Kevin M (https://experts.colorado.edu/display/fisid_128676)
Associate Professor; PhD, University of Wisconsin-Madison

Taylor, John
Professor Emeritus

Uzdensky, Dmitri Anatoljevich (https://experts.colorado.edu/display/fisid_147430)
Associate Professor; PhD, Princeton University

Wagner, Stephen R (https://experts.colorado.edu/display/fisid_139773)
Professor Attendant Rank, Lecturer

Wyss, Walter
Professor Emeritus

Yin, Xiaobo (https://experts.colorado.edu/display/fisid_153484)
Assistant Professor; PhD, Stanford University

Zhong, Shijie (https://experts.colorado.edu/display/fisid_118396)
Professor; PhD, University of Michigan Ann Arbor

Zimmerman, Eric (https://experts.colorado.edu/display/fisid_122809)
Professor; PhD, University of Chicago

Courses

PHYS 5030 (3) Intermediate Mathematical Physics 1
This course and its continuation, PHYS 5040, form a survey of classical mathematical physics. Studies complex variable theory and finite vector spaces, and includes topics in ordinary and partial differential equations, boundary value problems, potential theory, and Fourier analysis.
Equivalent - Duplicate Degree Credit Not Granted: MATH 5030
Requisites: Restricted to graduate students only.

PHYS 5040 (3) Intermediate Mathematical Physics 2
Continuation of PHYS 5030. Includes group theory, special functions, integral transforms, integral equations and calculus of variations.
Equivalent - Duplicate Degree Credit Not Granted: MATH 5040
Requisites: Restricted to graduate students only.
Recommended: Prerequisite PHYS 5030.

PHYS 5130 (3) Biological Electron Microscopy: Principles and Recent Advances
Covers basic mechanisms for imaging and recent advances used in current biological research, elements of electron optics, image optimization, resolution, radiation damage, various imaging modes (TEM, STEM, SEM, STEM, STM), specimen quantitation and reconstruction (stereo and 3-D), microanalysis and electron diffraction. Specimen preparation treated only incidentally.
Equivalent - Duplicate Degree Credit Not Granted: PHYS 4130

PHYS 5141 (3) Astrophysical and Space Plasmas
Covers magnetohydrodynamics and a few related areas of plasma physics applied to space and astrophysical systems, including planetary magnetospheres and ionospheres, stars, and interstellar gas in galaxies.
Equivalent - Duplicate Degree Credit Not Granted: ASTR 5140
Requisites: Restricted to Physics (PHYS) or Astronomy (ASTR) graduate students only.

PHYS 5150 (3) Introductory Plasma Physics
Includes basic phenomena of ionized gases, static and dynamic shielding, linear waves, instabilities, particles in fields, collisional phenomena, fluid equations, collisionless Boltzmann equations, Landau damping, scattering and absorption of radiation in plasmas, elementary nonlinear processes, WKB wave theory, controlled thermonuclear fusion concepts, astrophysical applications and experimental plasma physics (laboratory). Department enforced prerequisite: PHYS 3310. Instructor consent required for undergraduates.
Equivalent - Duplicate Degree Credit Not Granted: ASTR 5150
Requisites: Restricted to graduate students only.

PHYS 5160 (3) Fundamentals of Optics and Lasers
Covers the basic physics of lasers. Topics include basics of optical resonators and gaussian beam propagation, stimulated emission, laser threshold conditions, laser linewidth, q-switching and mode locking of lasers, tuning of Cw lasers, and specifics of various common lasers.
Requisites: Restricted to graduate students only.

PHYS 5210 (3) Theoretical Mechanics
Variational principles, Lagrange's equations, Hamilton's equations, motion of rigid body, relativistic mechanics, transformation theory, continuum mechanics, small oscillations, Hamilton-Jacobi theory.
Requisites: Restricted to graduate students only.

PHYS 5250 (3) Introduction to Quantum Mechanics 1
Quantum phenomena, Ehrenfest theorem and relation to classical physics, applications to one-dimensional problems, operator techniques, angular momentum and its representations, bound states and hydrogen atom, and Stern-Gerlack experiment and spin and spinor wave function. Department enforced prerequisite: advanced undergraduate quantum mechanics course.
Requisites: Restricted to graduate students only.

PHYS 5250 (3) Introduction to Quantum Mechanics 2
Symmetries and conservation laws, identical particle systems, approximation techniques (including time-dependent and time-independent perturbation theories and variational techniques) and their applications, scattering theory, radiative transitions, and helium atom.
Requisites: Restricted to graduate students only.
Recommended: Prerequisite PHYS 5250.
PHYS 5430 (3) Advanced Laboratory
Two lectures, one lab per week. Experiments introduce students to realities of the experimental physics so they gain a better understanding of theory and an appreciation of the vast amount of experimental work done in the physical sciences today. Department enforced prerequisites: PHYS 3330 and PHYS 3220 and PHYS 3320. Department enforced corequisites: PHYS 4410.
Equivalent - Duplicate Degree Credit Not Granted: PHYS 4430
Requisites: Restricted to graduate students only.

PHYS 5450 (3) History and Philosophy of Physics
Investigates the role of experiment in physics; case studies in the history and philosophy of physics and in scientific methodology.
Equivalent - Duplicate Degree Credit Not Granted: PHYS 4450 and PHYS 4460 and PHYS 5450
Requisites: Restricted to graduate students only.

PHYS 5460 (3) Teaching and Learning Physics
Learn how people understand key concepts in physics. Through examination of physics content, pedagogy and problems, through teaching, and through research in physics education, students will explore the meaning and means of teaching physics. Students will gain a deeper understanding of how education research is done and how people learn. Useful for all students, especially for those interested in physics, teaching, and education research.
Equivalent - Duplicate Degree Credit Not Granted: PHYS 4460 and EDUC 4460 and EDUC 5460
Requisites: Restricted to graduate students only.

PHYS 5550 (3) Cells, Molecules and Tissues: A Biophysical Approach
Focuses on the biophysics governing the structure/function of enzymes, cells, extracellular matrix and tissue. Synthesizes ideas from molecular biology, physics, and biochemistry, emphasizing how low Reynolds number physics, not Newtonian physics, is relevant to life inside a cell.
Equivalent - Duplicate Degree Credit Not Granted: PHYS 4550 and MCDB 4550 and MCDB 5500

PHYS 5560 (3) Introduction to Biophysics
Covers an introduction to the physics of living systems. Focuses on how living systems are able to generate order, with both physical principles and biological examples. Covers the development of quantitative models for biological systems, including estimates. Taught from a physics perspective, with biology background introduced as needed.
Equivalent - Duplicate Degree Credit Not Granted: PHYS 4560 and MCDB 4560 and MCDB 5560
Grading Basis: Letter Grade

PHYS 5606 (3) Optics Laboratory
Consists of 13 optics experiments that introduce the techniques and devices essential to modern optics, including characterization of sources, photodetectors, modulators, use of interferometers, spectrometers and holograms, and experimentation of fiber optics and Fourier optics.
Equivalent - Duplicate Degree Credit Not Granted: ECEN 5606
Recommended: Prerequisite undergraduate optics course such as PHYS 4510.

PHYS 5770 (3) Gravitational Theory (Theory of General Relativity)
Presents Einstein's relativistic theory of gravitation from geometric viewpoint; gives applications to astrophysical problems (gravitational waves, stellar collapse, etc.). Instructor consent required for undergraduates.
Requisites: Restricted to graduate students only.
Recommended: Prerequisites PHYS 3220 and PHYS 3320.

PHYS 5840 (1-3) Selected Topics for Graduate Independent Study
Subject matter to be arranged.
Repeatable: Repeatable for up to 7.00 total credit hours. Allows multiple enrollment in term.

PHYS 5970 (3) Seminar: Physical Methods in Biology
Covers basic mechanisms and applications of physical methods used in current biological research, microprobe analysis, Eels, elementary electron and x-ray crystallography, biomedical imaging (NMR, MRI, Pe, Cat), Fourier analysis, synchrotron radiation, Xeas, neutron scattering and novel ultramicroscopy techniques. Includes lectures, student presentations, occasional demonstrations. Emphasis depends on student interest.
Equivalent - Duplicate Degree Credit Not Granted: PHYS 4970
Requisites: Restricted to graduate students only.

PHYS 6260 (3) Geometry of Quantum Fields and Strings
Focuses on differential geometric techniques in quantum field and string theories. Topics include: spinors, Dirac operators, index theorem, anomalies, geometry of superspace, supersymmetric quantum mechanics and field theory and nonperturbative aspects in field and string theories.
Equivalent - Duplicate Degree Credit Not Granted: MATH 6260
Recommended: Prerequisites MATH 6230 and PHYS 5250 and MATH 6240 and PHYS 7280.

PHYS 6610 (3) Earth and Planetary Physics 1
Examines mechanics of deformable materials, with applications to earthquake processes. Introduces seismic wave theory. Other topics include inversion of seismic data for the structure, composition and state of the interior of the Earth.
Equivalent - Duplicate Degree Credit Not Granted: GEOL 6610 and ASTR 6610
Requisites: Restricted to graduate students only.

PHYS 6620 (3) Earth and Planetary Physics 2
Covers space and surface geodetic techniques as well as potential theory. Other topics are the definition and geophysical interpretation of the geoid and of surface gravity anomalies; isostasy; post-glacial rebound; and tides and the rotation of the Earth.
Equivalent - Duplicate Degree Credit Not Granted: GEOL 6620 and ASTR 6620
Requisites: Restricted to graduate students only.

PHYS 6630 (3) Earth and Planetary Physics 3
Examines the solar system, emphasizing theories of its origin and meteorites. Highlights distribution of radioactive materials, age dating, heat flow through continents and the ocean floor, internal temperature distribution in the Earth, and mantle convection. Also covers the origin of the oceans and atmosphere.
Equivalent - Duplicate Degree Credit Not Granted: GEOL 6630 and ASTR 6630
Requisites: Restricted to graduate students only.

PHYS 6650 (1-3) Seminar in Geophysics
Advanced seminar studies in geophysical subjects for graduate students.
Equivalent - Duplicate Degree Credit Not Granted: GEOL 6650 and GEOL 6650
Requisites: Restricted to graduate students only.

PHYS 6655 (3) InSAR Processing and Interpretation
Understand the concepts and applications of interferometric synthetic aperture radar (InSAR) and differential InSAR, to include an introduction to physical geodesy and satellite techniques.
Equivalent - Duplicate Degree Credit Not Granted: GEOL 6655
Grading Basis: Letter Grade
**PHYS 6670 (2) Geophysical Inverse Theory**
Principles of geophysical inverse theory as applied to problems in the Earth sciences, including topography, Earth structure and earthquake locations.

**Equivalent - Duplicate Degree Credit Not Granted:** GEOL 6670

**Requisites:** Restricted to graduate students only.

**PHYS 6940 (1) Master's Degree Candidate**
Approved problem in theoretical or experimental physics under the direction of staff members. Intended to introduce the student to procedures in research and development work. Work of an original nature expected.

**Grading Basis:** Pass/Fail

**PHYS 6950 (1-6) Master's Thesis**
Approved problem in theoretical or experimental physics under the direction of staff members. Intended to introduce the student to procedures in research and development work. Work of an original nature expected.

**Repeatable:** Repeatable for up to 6.00 total credit hours.

**Requisites:** Restricted to graduate students only.

**PHYS 7160 (3) Intermediate Plasma Physics**
Continuation of PHYS 5150. Topics vary yearly but include nonlinear effects such as wave coupling, quasilinear relaxation, particle trapping, nonlinear Landau damping, collisionless shocks, solutions; nonneutral plasmas; kinetic theory of waves in a magnetized plasma; anisotropy, inhomogeneity; radiation-ponderomotive force, parametric instabilities, stimulated scattering; plasma optics; kinetic theory and fluctuation phenomena.

**Equivalent - Duplicate Degree Credit Not Granted:** ASTR 7160

**Requisites:** Restricted to graduate students only.

**Recommended:** Prerequisite PHYS 5150.

**PHYS 7230 (3) Statistical Mechanics**
Classical and quantum statistical theory, including study of both equilibrium and nonequilibrium systems. Topics covered include kinetic theory, degenerate gases, macrocanonical and grand canonical ensembles, and irreversible processes. Department enforced prerequisite: advanced undergraduate quantum mechanics course.

**Requisites:** Restricted to graduate students only.

**PHYS 7240 (3) Advanced Statistical Mechanics**
Introduces current research topics in statistical mechanics. Topics vary from year to year and may include phase transitions, critical phenomena, nonequilibrium phenomena, dense fluids, dynamical systems, plasma physics, or quantum statistical mechanics.

**Requisites:** Restricted to graduate students only.

**Recommended:** Prerequisite PHYS 7230.

**PHYS 7250 (3) Quantum Many Body Theory**
Theory of quantum many body systems, including methods based on Green’s functions, Feynman diagrams, and coherent state path integral with applications to interacting quantum gases, superconductivity and superfluidity, quantum phase transitions, quantum magnetism, quantum motion in the presence of disorder, and topological states of matter.

**Requisites:** Restricted to graduate students only.

**PHYS 7270 (3) Introduction to Quantum Mechanics 3**
Radiation theory; relativistic wave equations with simple applications; introduction to field theory and second quantization.

**Requisites:** Restricted to graduate students only.

**PHYS 7280 (3) Advanced Quantum Theory**
Quantum theory of fields, elementary particles, symmetry laws, and topics of special interest.

**Requisites:** Restricted to graduate students only.

**Recommended:** Prerequisite PHYS 7270 or instructor consent required.

**PHYS 7310 (3) Electromagnetic Theory 1**
Sophisticated approach to electrostatics, boundary value problems, magnetostatics, applications of Maxwell’s equations to electromagnetic wave propagation, wave guides, and resonant cavities and magnetohydrodynamics.

**Requisites:** Restricted to graduate students only.

**PHYS 7320 (3) Electromagnetic Theory 2**
Continuation of PHYS 7310. Topics include relativistic particle dynamics; radiation by moving charges; multiple fields; radiation damping and self-fields of a particle; collisions between charged particles and energy loss; radiative processes; and classical field theory.

**Requisites:** Restricted to graduate students only.

**Recommended:** Prerequisite PHYS 7310.

**PHYS 7430 (3) Soften Condensed Matter Physics**
Introduces the science of liquid crystals, polymers, biological membranes, biopolymers, block copolymers, molecular monolayers, colloids, nanoparticle suspensions, emulsions, foams, gels, elastomers and other soft materials. Topics vary from semester to semester and is geared toward graduate students with diverse preparation backgrounds, including students from the Department of Physics, as well as other science and engineering departments.

**Requisites:** Restricted to graduate students only.

**PHYS 7440 (3) Theory of the Solid State**
Stresses application to the solid state of physical concepts basic to much of modern physics, single-particle approximation, and the energy-band description of electron states in solids, pseudopotential theory applied to ordered and disordered systems, dynamical behavior of electrons in solids, lattice dynamics, Hartree-Fock and random-phase approximation in solids, many-body aspects of magnetism, and superconductivity.

**Requisites:** Restricted to graduate students only.

**PHYS 7450 (3) Theory of Solid State 2**
Second semester of condensed matter physics, covers topics in soft condensed matter physics, liquid crystals, semiconductors, Quantum Hall effect, Fractional Quantum Hall effect, superconductivity and other topics at the discretion of the instructor.

**Requisites:** Restricted to graduate students only.

**PHYS 7550 (3) Atomic and Molecular Spectra**
Covers theory of atomic structure and spectra, including coupling of angular momenta, tensor operators, energy levels, fine and hyperfine structure, transition probabilities, Zeeman and Stark effects. Molecular spectra: electronic, vibrational, and rotational states. Rotation matrices, symmetric top.

**Requisites:** Restricted to graduate students only.

**PHYS 7560 (3) Quantum Optics**
Covers quantum optical and atomic systems including topics such as: coherent and squeezed states, theory of optical coherence, atom-radiation interaction, optical Bloch equations, open quantum systems, dynamics on the Bloch sphere, resonance fluorescence, beam-splitters and interferometry, entanglement and quantum information.

**Requisites:** Restricted to graduate students only.

**Recommended:** Prerequisites PHYS 3220 and PHYS 4410.
PHYS 7650 (3) Nonlinear and Nano-Optics
Covers the field of ultrafast optics including both experimental and theoretical aspects. Topics include: description of ultrashort optical pulses, propagation of pulses including dispersion and nonlinearity, their integration, measurement and manipulation and their use in applications including spectroscopy.
Requisites: Restricted to graduate students only.
Recommended: Prerequisites PHYS 4510 or PHYS 5160.
Grading Basis: Letter Grade

PHYS 7660 (3) Ultrafast Optics
Covers the field of ultrafast optics including both experimental and theoretical aspects. Topics include description of ultrashort optical pulses, propagation of pulses including dispersion and nonlinearity, their generation, measurement and manipulation and their use in applications including spectroscopy. Department enforced prerequisite: PHYS 5160, or PHYS 4510, or ECEN 5645.
Requisites: Restricted to graduate students only.

PHYS 7730 (3) Theory of Elementary Particles
Systematics of elementary particles, leptons, quarks, gauge bosons, symmetries and symmetry breaking, scattering cross sections, decay rates, electron-positron annihilation, lepton scattering and hadron structure, quantum chromodynamics, electroweak interactions, gauge theories.
Requisites: Restricted to graduate students only.

PHYS 7810 (1-3) Special Topics in Physics
Various topics not normally covered in the curriculum; offered intermittently depending on student demand and availability of instructors.
Repeatable: Repeatable for up to 7.00 total credit hours. Allows multiple enrollment in term.
Requisites: Restricted to graduate students only.

PHYS 7820 (3) Topics in Scientific Writing
Teaches strategies used in scientific writing with emphasis on problem statement, audience analysis and principles of sound argument; reviews and reinforces essential writing skills, stressing the need for careful and strategic revision; provides experience in writing academic and professional communications; presentation skills and proposal writing. Most appropriate for students beginning to write journal articles, Comps II paper, or dissertation chapter.
Requisites: Restricted to graduate students only.

PHYS 7830 (1-3) Plasma Seminar
One credit 'journal club' style course covering current and significant historical advances in plasma physics research. Each week the class is assigned a journal article to read in advance of the meeting and one student is selected (on a rotating basis) to present a synopsis and lead a round-table discussion. Cannot be used for minimum credit hour requirements of graduate program. See also PHYS 7810 and PHYS 7820. May be repeated for a total of 7 credit hours.
Repeatable: Repeatable for up to 7.00 total credit hours. Allows multiple enrollment in term.
Grading Basis: Pass/Fail

PHYS 7840 (1-3) Selected Topics for Graduate Independent Study
Subject matter to be arranged.
Repeatable: Repeatable for up to 7.00 total credit hours. Allows multiple enrollment in term.

PHYS 7850 (1-3) Selected Topics for Graduate Independent Study
Subject matter to be arranged. May be repeated for a total of 7 credit hours.
Repeatable: Repeatable for up to 7.00 total credit hours. Allows multiple enrollment in term.

PHYS 8990 (1-10) Doctoral Dissertation
All doctoral students must register for not fewer than 30 hours of dissertation credit as part of the requirements for the degree. For a detailed discussion of doctoral dissertation credit, refer to the Graduate School section.
Repeatable: Repeatable for up to 30.00 total credit hours.