

# Physics

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**Chair:** Miller, J. A., Professor

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The Physics department offers the following graduate degree programs:

- Master of Science
- Doctor of Philosophy
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## Admission Requirements

Refer to the Graduate Studies section of the Graduate Catalog for general admission and degree requirements. Additional information on Graduate Teaching and Research Assistantships is available on the department web site <http://physics.uah.edu>. Undergraduate preparation should include courses typically required for a Physics major, such as modern physics, quantum mechanics, and upper level classical mechanics, electrodynamics, and thermal physics.

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## Program Objective

The primary objective of the Physics department is to educate and train the next generation of physicists, perform cutting-edge and internationally-recognized research, and support the education of students in allied areas such as engineering, chemistry, atmospheric science, and the biological sciences. Our second objective prepares Physics majors for employment in industrial research or for further graduate studies in physics or related fields, including astrophysics, optics, biophysics, engineering, or medicine.

## Learning Outcomes

Students will:

- Exhibit a post-graduate level of knowledge in general physics topics
- Conduct a focused and thorough investigation of a topic and effectively communicate the results in a timely manner
- Possess the preliminary experience necessary for working in the private sector, academia, or industry

## Master's Program in Physics

There are three M.S. options in Physics:

- Thesis
- Non-thesis
- Secondary Education Certification

Required core courses for each are:

|        |  |   |
|--------|--|---|
| PH 601 | CLASSICAL DYNAMICS I                         | 3 |
| PH 607 | MATHEMATICAL METHODS I                       | 3 |
| PH 609 | MATHEMATICAL METHODS II                      | 3 |
| PH 621 | STAT MECH KINETIC THRY I                     | 3 |
| PH 631 | ELECTROMAGNETIC THEORY I                     | 3 |
| PH 651 | QUANTUM MECHANICS I                          | 3 |
| PH 652 | QUANTUM MECHANICS II                         | 3 |
| PH 792 | PHYSICS SEMINAR (two semesters) <sup>1</sup> | 1 |
| PH 792 | PHYSICS SEMINAR                              | 1 |

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**Total Semester Hours**

**23**

<sup>1</sup> All M.S. students are required to complete two semesters of PH 792 with a grade of "S"; these semester hours do not, however, count toward minimum degree requirements given below.

Students should complete a Program of Study with the help of their faculty advisor before the completion of 12 semester hours of graduate coursework. A Program of Study is a detailed list of courses that the student will take to satisfy the appropriate degree requirements.

## M.S. with Thesis

A student must take at least 24 semester hours in graduate courses, plus at least 6 semester hours of PH 699 (<http://catalog.uah.edu/search/?P=PH%20699>), culminating in the successful defense of their thesis. Students writing a thesis do not need to take the Comprehensive Examination.

## Optics and Photonics Technology Curriculum

The OPT (PH) M.S. degree program is comprised of a minimum of 27 semester hours of graduate coursework, plus a minimum of 6 semester hours of PH 699 (<http://catalog.uah.edu/search/?P=PH%20699>). The thesis option is the only available route to the OPT degree. Students may pursue the OPT option through either the Physics Department (PH) or the Electrical & Computer Engineering Department (ECE). The OPT (PH) program of study, available on the Department website <http://physics.uah.edu>, meets the Department of Physics M.S. degree requirements and is suggested for students coming from a Physics background. Students in this category, having a Physics Department faculty member as an advisor, will be designated as having Physics as their "home" department. Courses have been chosen such that little or no prior graduate work in physics is required. The OPT degree program does not prepare the student for taking the Physics Comprehensive Exam or the OSE Preliminary Exam. Requirements for students seeking the OPT degree through the Electrical Engineering department, OPT (ECE), may be significantly different.

## M.S. without Thesis

A student must take at least 33 semester hours of graduate coursework, and achieve an M.S. passing grade on the Comprehensive Examination. This exam is offered every August, and also serves as the preliminary examination for the Ph.D. degree program. The Comprehensive Examination is on material covered in the core courses given above, and thus has sections dealing with quantum mechanics, electromagnetic theory and relativity and classical and statistical mechanics. Criteria for an M.S. or Ph.D. pass are given on the Department's web site.

For students in the Optical Science and Engineering (OSE) Ph.D. program who desire an M.S. degree in Physics, a passing grade on the OSE Preliminary Examination is an acceptable substitute for the Comprehensive Examination.

A full-time course schedule leading to the Comprehensive Exam at the start of the Fall semester of the second year is listed below.

### Year 1

| Fall                         |                          | Semester Hours |
|------------------------------|--------------------------|----------------|
| PH 607                       | MATHEMATICAL METHODS I   | 3              |
| PH 651                       | QUANTUM MECHANICS I      | 3              |
| PH 601                       | CLASSICAL DYNAMICS I     | 3              |
| PH 792                       | PHYSICS SEMINAR          | 1              |
| <b>Term Semester Hours:</b>  |                          | <b>10</b>      |
| Spring                       |                          | Semester Hours |
| PH 609                       | MATHEMATICAL METHODS II  | 3              |
| PH 652                       | QUANTUM MECHANICS II     | 3              |
| PH 631                       | ELECTROMAGNETIC THEORY I | 3              |
| PH 792                       | PHYSICS SEMINAR          | 1              |
| <b>Term Semester Hours:</b>  |                          | <b>10</b>      |
| Summer                       |                          | Semester Hours |
| PH 621                       | STAT MECH KINETIC THRY I | 3              |
| Elective                     |                          | 3              |
| <b>Term Semester Hours:</b>  |                          | <b>6</b>       |
| <b>Total Semester Hours:</b> |                          | <b>26</b>      |

## Nine (9) Remaining Semester Hours

The remaining 9 semester hours of graduate coursework can be taken in the Physics Department (for advanced study in optics, space physics, astrophysics, or planetary science) or from another department such as Atmospheric Science. Students need to consult with their advisor regarding the selection of topical elective courses.

## M.S. with Certification

With this option, also called the *Alternative Fifth-year Program* in the Education Department section of the Graduate Catalog, students are awarded an M.S. degree in Physics as well as Class A (Master's level) Teaching Certification by the State of Alabama. **We strongly encourage students to investigate this rewarding career option.**

This program is available to students who do not already have a Class B (baccalaureate level) Teaching Certification. Requirements are 27 graduate semester hours in Education courses and 24 graduate semester hours in Physics courses. The Education courses are specified in the Education Department section of this catalog, and include a high school internship. The Physics courses include the core courses above, plus 9 additional semester hours. Three of the 9 additional hours will be PH 679 the required Capstone Course for this M.S. option. Neither the Comprehensive Exam nor a thesis is required for this option. However, a thesis can replace the Capstone Course, if desired.

## Doctoral Program in Physics

To obtain the Ph.D. degree in physics, a student must satisfy all requirements of the Graduate School as well as those in the Department of Physics. The major steps toward a Ph.D. degree are as follows:

### 1. Take the required core courses and pass the Comprehensive Exam at the Ph.D. Level.

Required core courses for the Ph.D. degree are:

|                             |                          |           |
|-----------------------------|--------------------------|-----------|
| PH 601                      | CLASSICAL DYNAMICS I     | 3         |
| PH 607                      | MATHEMATICAL METHODS I   | 3         |
| PH 609                      | MATHEMATICAL METHODS II  | 3         |
| PH 621                      | STAT MECH KINETIC THRY I | 3         |
| PH 631                      | ELECTROMAGNETIC THEORY I | 3         |
| PH 651                      | QUANTUM MECHANICS I      | 3         |
| PH 652                      | QUANTUM MECHANICS II     | 3         |
| PH 732                      | ELECTROMAGNETIC TH II    | 3         |
| <b>Total Semester Hours</b> |                          | <b>24</b> |

The Comprehensive Exam is offered every August, and covers the material in the core courses given above except PH 732 (<http://catalog.uah.edu/search/?P=PH%20732>), which is usually taken after the Exam. There are sections dealing with quantum mechanics, electromagnetic theory and relativity, and classical and statistical mechanics. A full-time course schedule leading to the Comprehensive Exam at the start of the Fall semester of the second year is listed below.

Admission to the Ph.D. program in physics is granted upon passing the Comprehensive Examination at the Ph.D. level. Students are permitted two attempts to pass the Comprehensive Examination. A student who fails on the first attempt must retake the examination the following year. Full-time students are generally expected to take the exam for the first time at the start of their second year. Further details are found on the Department's (<http://uah.edu/physics>) website.

#### Year 1

| Fall                         |                          | Semester Hours |
|------------------------------|--------------------------|----------------|
| PH 607                       | MATHEMATICAL METHODS I   | 3              |
| PH 651                       | QUANTUM MECHANICS I      | 3              |
| PH 601                       | CLASSICAL DYNAMICS I     | 3              |
| PH 792                       | PHYSICS SEMINAR          | 1              |
| <b>Term Semester Hours:</b>  |                          | <b>10</b>      |
| Spring                       |                          |                |
| PH 609                       | MATHEMATICAL METHODS II  | 3              |
| PH 652                       | QUANTUM MECHANICS II     | 3              |
| PH 631                       | ELECTROMAGNETIC THEORY I | 3              |
| PH 792                       | PHYSICS SEMINAR          | 1              |
| <b>Term Semester Hours:</b>  |                          | <b>10</b>      |
| Summer                       |                          |                |
| PH 621                       | STAT MECH KINETIC THRY I | 3              |
| Elective                     |                          | 3              |
| <b>Term Semester Hours:</b>  |                          | <b>6</b>       |
| <b>Total Semester Hours:</b> |                          | <b>26</b>      |

### 2. Form a supervisory committee and a Program of Study.

Once the Comprehensive Examination is passed, a student should proceed to form a supervisory committee and prepare a Program of Study. A Program of Study will consist of

- a minimum of 48 credit hours of graduate coursework. A maximum of 9 semester hours of PH 699 (<http://catalog.uah.edu/search/?P=PH%20699>) from a completed M.S. degree with thesis may be allowed to count toward this 48 semester hour requirement.
- three semesters of PH 792 (<http://catalog.uah.edu/search/?P=PH%20792>) with a grade of "S". Seminar semester hours do not count toward the 48 credit hours above.
- at least 18 semester hours of PH 799 (<http://catalog.uah.edu/search/?P=PH%20799>). No more than 9 of these semester hours may be taken prior to passing the Qualifying Examination (see below), and PH 799 does not count toward the 48 credit hours of graduate coursework.

Courses in addition to those enumerated above can be selected in consultation with the student's advisory committee. Transfer of credit from other institutions requires approval of the advisory committee, the Department Chair, and the Graduate Dean.

### 3. Pass the Qualifying Examination.

After preliminary work on their chosen Ph.D. dissertation topic, the student must then pass the Ph.D. Qualifying Examination. This examination is conducted under the auspices of the Graduate School, and tests the student's general fitness for pursuing a research project in their chosen area and their general knowledge of Physics. There are written and oral components to this exam. The written part consists of the student's responses to questions submitted by their Committee; these questions can deal with the specific proposed research or the general area of research (such as optics or astrophysics, as covered, e.g., in the elective courses taken in this area). The oral part is a presentation and defense of the proposed research.

### 4. Complete and defend a research dissertation.

Each student must complete and successfully defend a research dissertation, which must be approved by the student's supervisory committee, the Chair of the Physics Department, the Dean of the College of Science, and the Dean of the Graduate School. A significant portion of the dissertation should be submitted for publication in an approved journal with international circulation.

#### PH 531 - INTRO TO PLASMA DYNAMICS

Semester Hours: 3

Single-particle motion in magnetic fields; fluid equations and fluid theory wave modes; MHD theory, stability, and wave modes; introduction to kinetic theory and hot plasma wave modes. (Same as MAE 531).

#### PH 541 - GEOMETRICAL OPTICS

Semester Hours: 3

Foundations and physics of geometrical optics, Fermat's principles and Huygen wavelets, refraction and reflection. The many forms of Snell's Law. Optical path lengths, geometrical wavefronts and rays. Ray tracing, ynu-chart and matrix methods. Gaussian imagery and paraxial optics, conjugate elements, cardinal points, and image-object relations. Stops and pupils, chief and marginal rays, vignetting, and the optical or Lagrange invariant. The y-ybar diagram, design of common systems: objectives, magnifiers, microscopes, collimators and detectors. Optical glasses and chromatic aberrations, wavefront and transverse aberrations, spot diagrams and ray fan plots. (Same as OSE 541 and EE 541.) Fall.

#### PH 542 - PHYSICAL OPTICS

Semester Hours: 3

Scalar and electromagnetic waves, polarization, coherence, reflection and refraction; two beam and multiple beam interference, interferometers, Fabry-Perots, thin films, diffraction, and absorption and dispersion. (Same as OSE 542 and EE 542.) Fall, Spring.

#### PH 544 - OPTOELECTRONICS

Semester Hours: 3

Review of polarized light, the Jones and Mueller calculi. Propagation of light in birefringent material. Modulation of light using electro-optic effect, Kerr effect, acousto-optic effect, and Faraday effect. Elements of photodetection and detectors, signal processing, and signal-to-noise. Design and analysis of beam scanners, optical rf-spectrum analyzer, optical sensors, and optical communication systems. (Same as OPT 444 and OPE 451.) Fall even years.

#### PH 546 - RADIOMETRY, DETECTORS & SOURCE

Semester Hours: 3

Theory and practice of radiometry and photometry. Blackbody radiation and Lambertian sources. The propagation of radiant energy in free space and through optical systems. Detector classes, responsivity, bandwidth, and noise. Power spectral density, properties of sources, photon noise. (Same as OPT 446, OSE 546.) Spring even years.

#### PH 551 - QUANTUM MECHANICS I

Semester Hours: 3

Waves and particles; wave packets and the uncertainty principle; Schrodinger's equation and wave mechanics; postulates of quantum mechanics; simple systems in one, two and three dimensions; the hydrogen atom; angular momentum and spin; numerical solutions of the Schrodinger equation. Prerequisites require undergraduate quantum mechanics course(s).

**PH 553 - INTRO TO PARTICLE PHYSICS**

Semester Hours: 3

Survey of elementary particle physics with emphasis on the Standard Model of quarks, leptons and gauge bosons. Lorentz transformations, four-vectors and relativistic kinematics, angular momentum and spin. Lifetimes, cross-sections and Feynman rules. Quantum electro- and chromo-dynamics, Dirac equation and renormalization. Physics beyond the Standard Model.

**PH 560 - INTRO TO SOLID STATE PHYSICS I**

Semester Hours: 3

Crystal binding and crystal structure. Crystal structure determination. Phonons and lattice vibrations. Free electron gas. Electronic energy band theory. Prerequisite with concurrency: PH 551. (Same as MTS 660.) Fall, even years.

**PH 561 - INTRO TO SOLID STATE PHYSICS II**

Semester Hours: 3

Thermal properties of solids. Electronic properties, optical properties, electronic properties in a magnetic field, semiconductor devices, magnetism, superconductivity, defects and alloys, dislocations and crystal growth, non-crystalline solids, surfaces and interfaces. (Same as MTS 661.) Spring, odd years.

**PH 570 - OPT & PHOTONIC SYSTEMS DESIGN**

Semester Hours: 3

Review of paraxial optics, ray tracing codes, aberration and diffraction calculations; acousto- and electro-optic modulators, spatial light modulators; fibers, fiber splicers and connectors; gratings and diffractive optical elements; laser and light emitting diodes, photodetectors and CCD arrays; correlator systems; optical communication networks; signal processing systems design. Fall, even years.

**PH 571 - STELLAR ASTROPHYSICS**

Semester Hours: 3

Structure and physical processes of stars from the interior to the atmosphere: energy production and transfer, atmospheric properties, and observed spectral features. Models for stellar structure. Star formation and evolution, including the effects of a companion. Prerequisites: upper level undergraduate astrophysics course, and upper level undergraduate E&M course.

**PH 572 - GALAXIES & COSMOLOGY**

Semester Hours: 3

Galactic structure; Oort's constants; rotation curves; galaxy types; structure formation and evolution; Hubble expansion; Friedmann equation; cosmic microwave background; radiation and matter eras; primordial nucleosynthesis; dark matter/energy issues; development of structure in the early universe; horizon & flatness problems; inflation. Prerequisite: PH 571 or advanced undergraduate Astrophysics course, suggested PH 553, PH 621. Spring, odd years.

**PH 574 - INTRO TO GENERAL RELATIVITY**

Semester Hours: 3

An introductory course on general relativity and gravitational physics. General relativistic phenomena as inferred from the behavior of particles and light rays for a selection of spacetimes. Major properties of such objects as black holes, wormholes, gravitational waves, and the universe as a whole. Prerequisites: Undergraduate level special relativity and classical mechanics.

**PH 579 - OBSERVATIONAL ASTROPHYSICS**

Semester Hours: 3

Astronomical coordinate systems and time; spherical astronomy; telescope designs; basic optics; CCDs; infrared arrays; observational calibration and noise; high resolution imaging techniques (e.g., adaptive optics); spectroscopy; and high and low energy observational techniques (e.g., X-ray telescopes, radio interferometry). Students will also conceive their own projects, write observing proposals, and convene as a Time Allocation Committee to review proposals and schedule telescope time. Students will acquire, reduce, analyze and interpret data from one of the allocated projects, and present the results in a short paper. Prerequisites: upper-level undergraduate astrophysics courses.

**PH 589 - SELECTED TOPICS**

Semester Hours: 3

**PH 601 - CLASSICAL DYNAMICS I**

Semester Hours: 3

Variational principles and Lagrangian mechanics, rigid body motion, Hamilton's equations, and theory of small oscillations. Aspects related to modern physics. Fall.

## PH 607 - MATHEMATICAL METHODS I

Semester Hours: 3

Review of vector calculus and coordinate systems, introduction to tensors, matrices, infinite series, complex variables with applications to calculus of residues, partial differential equations, and Sturm-Liouville theory. Orthogonal functions, gamma functions, Bessel functions, Legendre functions, special functions, Fourier series, integral transforms and equations. Prerequisite: upper level undergraduate differential equations courses (s). (Same as MA 607.) Fall.

## PH 609 - MATHEMATICAL METHODS II

Semester Hours: 3

Continuation of PH 607. (Same as MA 609.) Spring.

## PH 615 - INTRO TO RADIOLOGICAL PHYSICS

Semester Hours: 3

## PH 616 - PHYSICS OF RADIATION THERAPY

Semester Hours: 3

Operation of X-ray tubes, electron linear accelerators, cobalt-60 units, cyclotrons. Principles of accelerating waveguides, klystrons, magnetrons, electron scattering foils, flattening filters, monitor chambers, collimators. Percent-depth-dose (PDD), tissue-phantom-ratio (TPR), tissue-air-ratio (TAR), peak scatter factor (PSF). Equivalent squares, calculation of monitor units for specific dose rates, collimator scatter factor ( $S_c$ ), phantom scatter factor ( $S_p$ ). Principles of brachytherapy: calibration of sources, absorbed dose using AAPM TG-43 protocol. Calculation of isodose distributions: convolution/superposition, Monte Carlo calculations. Intensity modulated radiation therapy (IMRT), stereotactic radiosurgery, tomotherapy, total-body irradiation.

## PH 621 - STAT MECH KINETIC THRY I

Semester Hours: 3

Statistical methods, systems of particles, statistical thermodynamics, applications of thermodynamics, methods of statistical mechanics, applications of statistical mechanics, equilibrium between phases of chemical species. Summer.

## PH 622 - STAT MECH KINETIC THRY II

Semester Hours: 3

Addresses the statistical description of collective processes in gases, plasmas, and fields based on the use of transport theory. The course provides the basis for the mathematical description of the basic kinetic and continuum models used in all fields of solar, space and astrophysics. Addresses specifically the transport of gases and Chapman-Enskog theory, magnetohydrodynamics in a collisional description, energetic particle transport in collisionless plasma, the transport of low-frequency turbulence, and if time permits, the transport of radiation.

## PH 631 - ELECTROMAGNETIC THEORY I

Semester Hours: 3

Electrostatic and magnetostatic fields in vacuum and materials, Maxwell's equations, electromagnetic waves. Prerequisites: upper level undergraduate E&M course(s), PH 607. Fall.

## PH 632 - FOURIER OPTICS

Semester Hours: 3

Introducing the optical system as an invariant linear system, convolution, Sommerfield's diffraction integral, Fourier Transform, angular spectrum, coherent and incoherent imaging, optical transfer function. Prerequisite PH 542 (Same as OSE 632 and EE 632.) Spring.

## PH 636 - INTRO TO SPACE PLASMA PHYSICS

Semester Hours: 3

Electromagnetic fields and particles in space; solar wind and solar energetic particles; currents and plasma waves in space; shocks and particle acceleration mechanisms; solar flares and coronal mass ejections. Spring, even years.

## PH 642 - OPTICAL PHYSICS

Semester Hours: 3

Fundamental physics of optics and optical phenomena. Electromagnetic fields, sources and propagation. Coherence, interference, polarization, scattering, reflection, refraction, and diffraction. Optical properties of conductors and insulators. Introduction to quantum optics, lasers, and optical device physics. Offered Spring, even years.

**PH 645 - LASERS I**

Semester Hours: 3

Incoherent light sources; atomic and molecular energy levels; equation of motion for probability amplitudes using first-order time dependent perturbation theory; electric dipole interaction. Einstein rate equations and the Planck radiation law; induced dipole moments and frequency-dependent susceptibility. Homogeneous and inhomogeneous line broadening mechanisms; laser cavities and modes, elementary laser theory, practical lasers. Prerequisite: upper level undergraduate E&M courses. (This course may be substituted for OSE 645.) Summer.

**PH 651 - QUANTUM MECHANICS I**

Semester Hours: 3

Free particle motion. Principles of wave mechanics. The Schrodinger equation and one-dimensional potentials. Approximation techniques: WKB, variational method, perturbation theory. Numerical methods. Prerequisites: undergraduate quantum mechanics or modern physics, some high-level programming (e.g., C++, Fortran, Mathematica) experience. Prerequisite with concurrency: PH 607.

**PH 652 - QUANTUM MECHANICS II**

Semester Hours: 3

Spherically-symmetric potentials, angular momentum, spin. Identical particles. Time-dependent perturbation theory. Scattering. Atomic structure. Prerequisite: PH 651. Prerequisite with concurrency: PH 609.

**PH 654 - OPTICAL TESTING**

Semester Hours: 3

Spherometry; refractive index measurements; optical bench measurements of imaging systems via T-bar nodal slide (effective focal length, f-number, axial color, field curvature and distortion, transverse ray aberrations); illumination falloff; image resolution tests (finite object); modulation transfer function; star image testing; knife edge tests; Hartmann tests; Fizeau interferometer and testing configurations; null lens testing of aspheres; wavefront measurements (point diffraction interferometer, radial shear interferometer); (Same as OSE 654.) Spring.

**PH 655 - APPLIED QUANTUM MECHANICS**

Semester Hours: 3

Application of quantum mechanics in solid state, electronics, materials science, and optics. Topics to include: Hydrogen atom and molecule, excitons, phonons, Bloch's theorem, periodic boundary conditions, electrons and holes, band structure of simple semiconductors, dipole transitions, optical constants, absorption and emission processes. Introduction to device physics. (Same as OSE 655).

**PH 661 - DATA ANAL/STAT METH PH/ASTROPH**

Semester Hours: 3

Moments of a distribution, linear and non-parametric correlation, central limit theorem, error estimation, least squares modeling, estimating model parameters, Monte Carlo techniques. Bayes' theorem and likelihood methods. Energy and temporal spectral analyses. Power density spectra: periodic and quasi-periodic systems. Prerequisite: upper level undergraduate mathematics courses. Fall, even years.

**PH 670 - OPTOMECHANICAL DESIGN & MANUF**

Semester Hours: 3

Practical aspects of optomechanical design, material selection, fabrication and integration of precision optical components and systems for commercial, space, and military applications. Topics include: fixture design, tolerance analysis, machining methods, thermal stabilization, integrated computer-aided design and analysis, diamond machining, finishing and plating techniques. (Same as OSE 670.) Fall, even years.

**PH 671 - OPTICAL FABRIC & TESTING**

Semester Hours: 3

Fabrication and testing techniques of optical components and systems. Component measurements: refractive index, curvature, focal lengths, cardinal points and field curvature. Wavefront aberration and transverse aberration function measurements: geometric tests, interferometric tests, null tests. Basics of grinding, figuring, polishing and optical coating. Laboratory experience in manufacturing, polishing, testing, and coating reflective or transmissive optics. Offered on demand.

**PH 673 - HIGH ENERGY ASTROPHYSICS**

Semester Hours: 3

Radiative Transfer: Blackbody, scattering and diffusion, bremsstrahlung, synchrotron emission, Compton scattering. Relativistic electromagnetism. Plasma effects and introduction to magnetohydrodynamics. Observational aspects of white dwarves, neutron stars and black holes. Accretion and astrophysical jets. Active galactic nuclei and gamma-ray bursts. Offered Fall of odd years.

PH 674 - GEN RELATIVITY & GRAVITATION I

Semester Hours: 3

Special and general relativity: vector and tensor calculus; curved manifolds; elements of differential geometry; physics in curved spacetime; the Einstein equations; simple solutions of the Einstein equations; Schwarzschild geometry and the Kerr spacetime; black holes; sources, propagation, and detection of gravitational waves; a variational approach to general relativity; special topics.

PH 679 - EDUCATION CAPSTONE COURSE

Semester Hours: 3

Capstone experience for student pursuing secondary education certification option for MS degree. Student develops 1 credit, 100 level physics course on instructor-approved topic. Development includes syllabus, textbook evaluation, representative homework assignments, midterm, final, lecture outline, and lecture notes.

PH 680 - SELECTED TOPICS

Semester Hours: 3

Offered upon demand. Topics include: optical surface characterization, superconductivity, aeronomy, properties of solids, laser propagation, collision theory, magnetohydrodynamics. Fall, Spring, Summer.

PH 681 - SELECTED TOPICS

Semester Hours: 3

Offered upon demand. Topics include: optical surface characterization, superconductivity, aeronomy, properties of solids, laser propagation, collision theory, magnetohydrodynamics. Fall, Spring, Summer.

PH 682 - SELECTED TOPICS

Semester Hours: 3

Offered upon demand. Topics include: optical surface characterization, superconductivity, aeronomy, properties of solids, laser propagation, collision theory, magnetohydrodynamics. Fall, Spring, Summer.

PH 683 - SELECTED TOPICS

Semester Hours: 3

Offered upon demand. Topics include: optical surface characterization, superconductivity, aeronomy, properties of solids, laser propagation, collision theory, magnetohydrodynamics. Fall, Spring, Summer.

PH 689 - SELECTED TOPICS

Semester Hours: 3

Offered upon demand. Topics include: optical surface characterization, superconductivity, aeronomy, properties of solids, laser propagation, collision theory, magnetohydrodynamics. Fall, Spring, Summer.

PH 699 - MASTER'S THESIS

Semester Hours: 3-6

Minimum of 6 credit hours required for Plan I M.S. students. Maximum of nine hours credit toward Ph.D. course requirements awarded upon successful completion of master's thesis. Fall, Spring, Summer.

PH 731 - ADVANCED PLASMA THEORY

Semester Hours: 3

Vlasov theory; electrostatic and electromagnetic waves in a hot plasma; wave damping processes; micro-instabilities; quasilinear theory; numerical simulation of plasmas; applications to space and astrophysics. Prerequisite: PH 531, experience with a high-level programming language. Spring, odd years.

PH 732 - ELECTROMAGNETIC TH II

Semester Hours: 3

Continuation of PH 631. Radiation from accelerated charges; Hamiltonian formulation of electrodynamics; covariant formulation of electrodynamics. Spring.

PH 733 - QUANTUM DEVICES

Semester Hours: 3

Quantum aspects of optical, electronic, and semiconductor devices approached from a phenomenological/physical point of view. Topics will include: Quantum well devices, optical modulators, optical detectors, quantum Stark effects, electrooptic devices, high speed optical devices, frequency chirping in high speed devices and system applications. (Same as OSE 755.) Fall, odd years.



**PH 745 - LASERS II**

Semester Hours: 3

The propagation of optical beams in homogeneous and lens-like media, optical resonators, interaction between radiation and atomic systems, laser oscillations and specific laser systems, qswitching and mode-locking of lasers, noise in laser amplifiers and oscillators, modulation of optical radiation. Fall, even years.

**PH 746 - NON-LINEAR OPTICS**

Semester Hours: 3

**PH 751 - COMPUTATIONAL QUANTUM MECH**

Semester Hours: 3

Numerical methods for solving the Schrodinger equation. Numerical approximation techniques: Rayleigh-Ritz theory. Quantum scattering from a spherically-symmetric potential. Multi-electron atoms: Hartree self-consistent field theory, Hartree-Fock theory, density functional theory. Electronic structure of diatomic molecules. Ab initio treatment of molecular structure. Additional extensive application to problems in molecular, atomic, and nuclear physics. Prerequisites: PH 652, high-level programming (e.g. C++, Fortran, Mathematica) experience. Offered on demand.

**PH 752 - QUANTUM MECHANICS II**

Semester Hours: 3

**PH 753 - QUANTUM FIELD THEORY**

Semester Hours: 3

Formalism of quantum field theory, construction and evaluation of Feynman diagrams for quantum electrodynamics and the weak interaction, first-order processes, renormalization, particle scattering and decay, nucleon structure, introduction to quantum chromodynamics, accelerator experiments, and astrophysical applications.

**PH 789 - SELECTED TOPICS**

Semester Hours: 3

Topics include superconductivity, advanced plasma theory, properties of solids, laser propagation, collision theory, quantum electronics, gravitational theories. Fall, Spring, Summer.

**PH 792 - PHYSICS SEMINAR**

Semester Hour: 1

Students attend seminars by invited speakers. Two semesters are required for all M.S. students and three semesters for Ph.D. students. Does not count toward minimum degree requirements. Fall, Spring.

**PH 795 - ADV PHYSICS PROJECT LAB**

Semester Hours: 3-6

Advanced laboratory research in one of the departmental research groups. Student works on an independent or group project. Completion of the course requires a written report that becomes part of the student's record. Fall, Spring, Summer.

**PH 799 - DOCTORAL DISSERTATION**

Semester Hours: 3-9

Prerequisites: Students must have passed the comprehensive examination at Ph.D. level and have Ph.D. advisor's approval. No more than 9 hours may be taken prior to passing the qualifying examination. Fall, Spring, Summer.

**PH ADD - GEN PHYSICS II & LAB/AL A&M**

Semester Hours: 4