Physics & Astronomy (PHYS)

Courses

PHYS 1011 21st-Century Physics and Astronomy I (4 Credits)
First class in a three-quarter sequence that explores the meaning of discoveries in our physical world in terms of astronomy and astrophysics, and how they shape modern research into our knowledge of the nature of the universe. In this course sequence, students (1) survey the fundamentals of the cutting-edge astronomy and astrophysics and (2) learn how physics works in explaining varieties of observed astronomical phenomena that encompass the origin and evolution of the universe and its contents--from galaxies to stars and planets. In this way students become familiar with the essential concepts of modern physics in terms of astronomy and astrophysics. Lab fee associated with these courses. This course counts toward the Scientific Inquiry: The Natural and Physical World requirement.

PHYS 1012 21st-Century Physics and Astronomy II (4 Credits)
Second class in a three-quarter sequence that explores the meaning of discoveries in our physical world in terms of astronomy and astrophysics, and how they shape modern research into our knowledge of the nature of the universe. In this course sequence, students (1) survey the fundamentals of the cutting-edge astronomy and astrophysics and (2) learn how physics works in explaining varieties of observed astronomical phenomena that encompass the origin and evolution of the universe and its contents--from galaxies to stars and planets. In this way students become familiar with the essential concepts of modern physics in terms of astronomy and astrophysics. Lab fee associated with these courses. This course counts toward the Scientific Inquiry: The Natural and Physical World requirement.

PHYS 1013 21st-Century Physics and Astronomy III (4 Credits)
Third class in a three-quarter sequence that explores the meaning of discoveries in our physical world in terms of astronomy and astrophysics, and how they shape modern research into our knowledge of the nature of the universe. In this course sequence, students (1) survey the fundamentals of the cutting-edge astronomy and astrophysics and (2) learn how physics works in explaining varieties of observed astronomical phenomena that encompass the origin and evolution of the universe and its contents--from galaxies to stars and planets. In this way students become familiar with the essential concepts of modern physics in terms of astronomy and astrophysics. Lab fee associated with these courses. This course counts toward the Scientific Inquiry: The Natural and Physical World requirement.

PHYS 1050 Descriptive Astronomy (4 Credits)
Introduction to the cosmos, including stars, galaxies, and origin and fate of universe; constellations and observing techniques. Includes laboratory and observing sessions at Chamberlin Observatory's 20-inch refractor telescope.

PHYS 1070 Solar System Astronomy (4 Credits)
Introduction to advances in knowledge of atmospheres, surfaces and interiors of other planets in our solar system and elsewhere; emphasis on interpretation and significance of discoveries for the nonspecialist. Includes observing at Chamberlin Observatory. Recommended Prerequisite: PHYS 1050.

PHYS 1090 Cosmology (4 Credits)
Companion to PHYS 1070. Discoveries of modern era concerning stars, galaxies, and origin and fate of universe, to aid appreciation of new discoveries. Open to majors and non-majors in the sciences. Includes scheduled observing at Chamberlin Observatory. Recommended Prerequisite: PHYS 1050.

PHYS 1111 General Physics I (5 Credits)
This is the first of a three-quarter sequence for students in any Natural Science and Mathematics field of study. The course stresses physics concepts rather than equation derivation as in the calculus-based course (PHYS 1211/PHYS 1212/PHYS 1213 or PHYS 1214). Algebra and trigonometry are used regularly to solve problems and make predictions. Includes topics in mechanics (kinematics, dynamics) including forces, one and two dimensional motion, work, energy and momentum. The course includes a rigorous algebra-based laboratory that exposes students to a broad range of the real physical phenomena investigated using equipment as well as computerized instrumentation and data acquisition techniques. This course counts toward the Scientific Inquiry: The Natural and Physical World requirement. Prerequisites: high school algebra, trigonometry. Students majoring in physics or engineering are required to take PHYS 1211/PHYS 1212/PHYS 1213 or PHYS 1214. Lab fee associated with this course.

PHYS 1112 General Physics II (5 Credits)
This is the second of a three-quarter sequence for students in any Natural Science and Mathematics field of study. The course stresses physics concepts rather than equation derivation as in the calculus-based course (PHYS 1211/PHYS 1212/PHYS 1213 or PHYS 1214). Algebra and trigonometry are used regularly to solve problems and make predictions. Includes topics in rotational motion, torque, vibrations, fluids, heat and thermodynamics, kinetic theory, and particles and matter waves. The course includes a rigorous algebra-based laboratory that exposes students to a broad range of the real physical phenomena investigated using equipment as well as computerized instrumentation and data acquisition techniques. This course counts toward the Scientific Inquiry: The Natural and Physical World requirement. Prerequisites: high school algebra, trigonometry. Students majoring in physics or engineering are required to take PHYS 1211/PHYS 1212/PHYS 1213 or PHYS 1214. Lab fee associated with this course.
PHYS 1113 General Physics III (5 Credits)
This is the third of a three-quarter sequence for students in any Natural Science and Mathematics field of study. The course stresses physics concepts rather than equation derivation as in the calculus-based course (PHYS 1211/PHYS 1212/PHYS 1213 or PHYS 1214). Algebra and trigonometry are used regularly to solve problems and make predictions. Includes topics in rotational motion, torque, vibrations, fluids, heat and thermodynamics, kinetic theory, and particles and matter waves. The course includes a rigorous algebra-based laboratory that exposes students to a broad range of the real physical phenomena investigated using equipment as well as computerized instrumentation and data acquisition techniques. This course counts toward the Scientific Inquiry: The Natural and Physical World requirement. Prerequisites: high school algebra, trigonometry. Students majoring in physics or engineering are required to take PHYS 1211/PHYS 1212/PHYS 1213 or PHYS 1214. Lab fee associated with this course.

PHYS 1200 Physics Preparatory (2 Credits)
This course is strongly recommended to everyone considering a major in physics and astronomy. It introduces students to problems, techniques, and tools used in physics and astronomy and offers an overview of the research carried out in the Department of Physics and Astronomy. High-school physics knowledge is not required.

PHYS 1211 University Physics I (5 Credits)
First of a three-quarter sequence. Kinematics, vectors, force, energy and work, linear momentum, rotation of rigid bodies. Required for all physics and engineering majors and recommended for all science majors who are also required to take calculus. The course includes a rigorous calculus-based laboratory that exposes students to a broad range of the real physical phenomena studied in the lecture course. Through the use of experimental apparatus, computerized instrumentation and data acquisition, data analysis and graphical representation, students use the observed phenomena to exemplify the laws of physics. Physics theory and other relevant background information are explored individually by students in weekly prelab exercises. Students learn to write introductory-level laboratory reports and become familiar with good laboratory technique. Emphasis for this lab is on mechanics. This course counts toward the Scientific Inquiry: The Natural and Physical World requirement. Corequisite: MATH 1951.

PHYS 1212 University Physics II (5 Credits)
Second of a three-quarter sequence. Gravitation, fluids; oscillatory motion; waves; thermal physics. Required for all physics and engineering majors and recommended for all science majors who are also required to take calculus. The lab portion of this course is a continuation of the PHYS 1211 lab portion and builds on laboratory skills and knowledge from that course. Emphasis for this lab is on waves, oscillations, sound, fluids and thermodynamics. This course counts toward the Scientific Inquiry: The Natural and Physical World requirement. Prerequisite: PHYS 1211. Corequisite: MATH 1952.

PHYS 1213 University Physics III (5 Credits)
Third of a three-quarter sequence. Electrostatics, electric circuits, magnetism and electromagnetism; electromagnetic waves. Required for all physics and engineering majors and recommended for all science majors who are also required to take calculus. The lab portion of this course is a continuation of the PHYS 1221 and 1222 lab portions and builds on the students’ laboratory skills and knowledge from those labs. Emphasis for this lab is on electricity, magnetism and circuits. This course counts toward the Scientific Inquiry: The Natural and Physical World requirement. Cross listed with PHYS 1214. Prerequisite: PHYS 1212. Corequisite: MATH 1953.

PHYS 1214 University Physics III for Engineers (4 Credits)
This is the third course of a three-quarter sequence and is for engineers only; this is equivalent to PHYS 1213, but does not include lab component. Electrostatics, electric circuits, magnetism and electromagnetism; electromagnetic waves. Required for all engineering majors. This course counts toward the Scientific Inquiry: The Natural and Physical World requirement. Cross listed with PHYS 1213. Prerequisite: PHYS 1212. Corequisite: MATH 1953.

PHYS 1991 Independent Study (1-10 Credits)
PHYS 1992 Directed Study (1-10 Credits)
PHYS 1995 Independent Research (1-10 Credits)

PHYS 2011 Circuits I (3 Credits)
Cross-listed with ENEE 2012. An introduction to electrical circuits analysis and design. Emphasis is on definitions of basic variables, passive circuit components and the ideal operational amplifier. DC analysis of circuits and circuit theorems are stressed. AC signals are introduced. Computer analysis software is integrated throughout the course. Cross listed with ENEE 2011. Co-requisites: PHYS 1213 or 1214, MATH 1953, PHYS 2015 or instructor's permission.

PHYS 2012 Circuits II (3 Credits)
Cross-listed with ENEE 2021. AC analysis of linear circuits to include circuit theorems via classical and transform techniques. Emphasis is on Laplace transform, including use of pole-zero and Bode diagrams to analyze and design circuits, including multiple filters (single-pole cascade, Butterwork, Chebyshev), and step response circuits. Phasors applications to sinusoidal steady state analysis and AC power. Computer analysis software is used as an aid to circuit design. Cross listed with ENEE 2021. Prerequisites: PHYS 2011, PHYS 2015. Corequisites: PHYS 2025, MATH 2070.

PHYS 2025 Engineering Applications II (1 Credit)
Cross-listed with ENEE 2025. Laboratory program practicing time and frequency domain analysis and design techniques on step response and filter problems. Applications to instrumentation and circuits. Cross listed with ENEE 2025. Prerequisite: PHYS 2011. Corequisite: PHYS 2021 or instructor's permission.
PHYS 2051 Bio-Astronomy of Solar Systems (4 Credits)
The nature of our solar system, and those of recently discovered solar systems around other stars, will be examined using the tools of modern physics and astronomy, with a focus on biogenic opportunities in these diverse environments. Credit can apply toward physics or astrophysics minor. Prerequisite: PHYS 1050 or PHYS 1070 or PHYS 1090 or PHYS 1111 or PHYS 1211 or instructor’s permission.

PHYS 2052 Stellar Physics (4 Credits)
The physics of stars will be examined using the tools of modern physics and astronomy, with the focus on their structure, interiors, origin and evolution, including single and multiple star systems, white dwarf, neutron stars and black holes. Credit can apply toward physics or astrophysics minor. Prerequisite: PHYS 1050 or PHYS 1070 or PHYS 1090 or PHYS 1111 or PHYS 1211 or instructor’s permission.

PHYS 2053 Galaxies and Cosmology (4 Credits)
Modern discoveries involving galaxies in our universe and cosmological theories based on these and particle physics findings will be examined using the tools of modern physics and astronomy. Credit can apply toward physics or astrophysics minor. Prerequisite: PHYS 1050 or PHYS 1070 or PHYS 1090 or PHYS 1111 or PHYS 1211 or instructor’s permission.

PHYS 2061 Telescopes and Instrumentation (4 Credits)
The student will develop and refine facility and experience with telescopes, software, methods, catalogs, libraries, astronomical instrumentation and assorted contents of the universe, including ground-based and space-based telescopes and detector systems. Observing projects included; use of the Student Astronomy Lab and/or internet telescope(s) for observing projects and variable star monitoring, plus occasional use of the 20 inch Clark/ Saegmuller reflector or Mt. Evans reflectors for observing, measuring and practicing public instruction. Math tools include algebra, statistics, Excel, Mathcad, IDL, C++, etc. Credit can apply toward physics or astrophysics minor. Prerequisite: PHYS 1050 or PHYS 1070 or PHYS 1090 or PHYS 1112 or PHYS 1212 or instructor’s permission.

PHYS 2062 Astronomy with Digital Cameras (4 Credits)
The revolution brought about with digital recording systems has revolutionized astronomy by providing access to faint source imaging and in-depth astronomical spectroscopy not possible during the photographic era. This course will train students to apply this technology to problems associated with light and spectrum measurement that facilitate tests of modern astrophysical theories. Each student will select an observing project to develop during the term, pursue data collection and analysis at the Student Astronomy Lab or other telescope(s), and report results on a personal website and/or in poster format. Credit can apply toward physics or astrophysics minor. Prerequisite: PHYS 1050 or PHYS 1070 or PHYS 1090 or PHYS 1113 or PHYS 1213 or instructor’s permission.

PHYS 2063 Observing & Data Analysis (4 Credits)
In this summer-only class, the student will learn fundamentals of astronomical research with hands-on observing and data analysis opportunities at DU’s Meyer-Womble Observatory located high atop Mt. Evans, 35 miles west of campus. Good health is essential to withstand the rigors of high altitude and nighttime work at this remarkable site. Contact the instructor for guidelines and details. Credit can apply toward physics or astrophysics minor. Prerequisite: PHYS 1050 or PHYS 1070 or PHYS 1090 or PHYS 1111 or PHYS 1211 or instructor’s permission.

PHYS 2110 Introduction to Computational Physics (3 Credits)
Application of computational mathematics packages and spreadsheet programs to a variety of physics problems; numerical differentiation and integration, solution of differential equations, matrix calculations, computer graphics. Includes lecture and laboratory. Prerequisites: PHYS 1113, PHYS 1213 or PHYS 1214 and MATH 1953.

PHYS 2251 Modern Physics I (4 Credits)
First of a two-quarter sequence. Topics covered: Introduction to special relativity; photons, de Broglie wavelength, Heisenberg uncertainty principles, quantum numbers and invariance principles; introduction to quantum physics of atoms, molecules, solids and nuclei; radioactive decay; elementary particles. Prerequisites: PHYS 1113, PHYS 1213 or PHYS 1214 and MATH 1953. Corequisite: MATH 2070.

PHYS 2252 Modern Physics II (4 Credits)

PHYS 2259 Uncertainty and Error Analysis (2 Credits)
In this course, students will build on the laboratory experience gained in University Physics Lab. Students will learn why uncertainty analysis is crucial to reducing and correcting errors in science. Additionally, students will develop the theory behind, and learn how to carry out, uncertainty and data analysis calculations. Uncertainty analysis topics include statistical analysis of data, propagation of error, the normal distribution, rejection of data, weighted averages, least-squares fitting, covariance and correlation, the binomial and Poisson distributions, and the chi-squared test. Strong emphasis for this course is placed on having students develop independence with their laboratory skills, as well as preparing students for Modern Physics Lab (PHYS 2260). Prerequisites: PHYS 1213 or PHYS 1214 and MATH 1953 or MATH 1963.

PHYS 2260 Modern Physics Lab (1 Credit)
Laboratory to accompany PHYS 2252. Students will perform laboratories that demonstrate special relativity, the wave/particle duality of light, the quantization of charge, and the discrete nature of energy levels in bound systems. Laboratories include the Michelson-Morley experiment, spectroscopy, blackbody radiation, laser diffraction and the double slit experiment, the photoelectric effect, the Millikan oil drop experiment, the charge-to-mass ratio of the electron, and the Franck-Hertz experiment. Students will apply uncertainty and error analysis to real experimental data. Strong emphasis for this lab is placed on having students develop independence with their laboratory skills. A Windows-based laptop computer is required for this lab. Lab fee associated with this course. Prerequisites: PHYS 2259 and MATH 2070. Corequisite: PHYS 2252.
PHYS 2300 Physics of the Body (3 Credits)
This is the first course required for a medical physics minor. Muscles and forces; physics of the skeleton; energy, heat, work and power of the body; osmosis and kidneys; lungs and breathing; cardiovascular system; electrical and magnetic signals in the body. Prerequisite: PHYS 1113, PHYS 1213, or PHYS 1214.

PHYS 2311 Intermediate Lab I (2 Credits)
In this lab, students learn to develop laboratory instrumentation to make physical measurements using electronic circuitry and the personal computer. Laboratory exercises include a review of DC circuits including transistors, LabVIEW programming, the PC parallel port, AC circuits and the oscilloscope, operational amplifiers and the RS-232C serial port. Strong emphasis for this lab is placed on having students develop independence with their laboratory skills. Prerequisites: PHYS 2260 and MATH 2070.

PHYS 2312 Intermediate Lab II (2 Credits)
This lab is a continuation of PHYS 2311 and builds heavily on the concepts learned during that first quarter. Laboratory exercises include using the personal computer, LabVIEW programming, and electronic circuitry for single point and waveform data acquisition including the Fast Fourier Transform, GPIB and serial devices, transducers, controls and feedback systems, counting, and timing. Strong emphasis for this lab is placed on having students develop independence with their laboratory skills. Prerequisite: PHYS 2311.

PHYS 2313 Intermediate Lab III (2 Credits)
This lab is the final lab in the Intermediate Lab sequence. Students leverage the knowledge gained in the first two quarters to perform physics experiments using electronic circuitry and the personal computer. It is expected that students will be independent in their ability to perform in the laboratory. Prerequisite: PHYS 2312.

PHYS 2340 Medical Imaging Physics (3 Credits)
This is the second course required for a medical physics minor, following Physics of the Body (PHYS 2300). X-rays; nuclear medicine instrumentation; radiography and fluoroscopy; computed tomography; ultrasound; magnetic resonance imaging; radiobiology. Prerequisites: PHYS 1113, PHYS 1213 or PHYS 1214 and PHYS 2300.

PHYS 2510 Applied Mechanics I (3 Credits)
First of a three-quarter sequence. Co-listed with ENME 2510. Statics of particles, equivalent systems of forces, centroids and center of gravity, frames and machines, friction, moments of inertia, method of virtual work. Kinematics of particles, Newton's second law, energy and momentum, central force motion, impulsive motion, kinematics and motion of rigid bodies in two and three dimensions; accelerated frames of reference; mechanical vibrations. Cross listed with ENME 2510. Prerequisite: PHYS 1211.

PHYS 2520 Applied Mechanics II (3 Credits)
Second of a three-quarter sequence. Statics of particles, equivalent systems of forces, centroids and center of gravity, frames and machines, friction, moments of inertia, method of virtual work. Kinematics of particles, Newton's second law, energy and momentum methods for particles and systems of particles, angular momentum, central force motion, impulsive motion, kinematics and motion of rigid bodies in two and three dimensions; accelerated frames of reference; mechanical vibrations. Cross listed with ENME 2520. Prerequisites: PHYS 2510, ENGR 3610.

PHYS 2530 Applied Mechanics III (3 Credits)
Third of a three-quarter sequence. Statics of particles, equivalent systems of forces, centroids and center of gravity, frames and machines, friction, moments of inertia, method of virtual work. Kinematics of particles, Newton's second law, energy and momentum methods from particles and systems of particles, angular momentum, central force motion, impulsive motion, kinematics and motion of rigid bodies in two and three dimensions; accelerated frames of reference; mechanical vibrations. Cross listed with ENME 2530. Prerequisites: PHYS 2520, ENGR 3610.

PHYS 2555 Mechanics I (4 Credits)
First of a two-quarter sequence. Topics include motion of a particle and of particle systems, conservative and nonconservative forces, statics and dynamics of rigid bodies, gravitation, moving coordinate systems, small vibrations and normal modes, and introduction to Lagrangian and Hamiltonian mechanics. Prerequisites: PHYS 1113, PHYS 1213, or PHYS 1214 and MATH 2070.

PHYS 2556 Mechanics II (4 Credits)
Second of a two-quarter sequence. Topics include motion of a particle and of particle systems, conservative and nonconservative forces, statics and dynamics of rigid bodies, gravitation, moving coordinate systems, small vibrations and normal modes, and introduction to Lagrangian and Hamiltonian mechanics. Prerequisite: PHYS 2555.

PHYS 2830 Natural Optics (3 Credits)
An investigation of naturally occurring optical phenomena with an emphasis on observational characteristics and causes. Prerequisite: PHYS 1113, PHYS 1213 or PHYS 1214 or instructor's permission.

PHYS 2991 Independent Study (1-10 Credits)
PHYS 2992 Directed Study (1-10 Credits)
PHYS 2995 Independent Research (1-10 Credits)
PHYS 3100 Senior Seminar (2 Credits)
This course offers primers on literature research, practices of a good scientific writing, putting together a good presentation or report, carrying out and documenting research, preparing for graduate program and/or job. Required for all Physics majors.
PHYS 3111 Quantum Physics I (4 Credits)
First of a two-quarter sequence. The Schrödinger equation: interpretation of wave functions; the uncertainty principle; stationary states; the free particle and wave packets; the harmonic oscillator; square well potentials. Hilbert space: observables, commutator algebra, eigenfunctions of a Hermitian operator; the hydrogen atom and hydrogenic atoms. Prerequisites: PHYS 2252, PHYS 2260, PHYS 2556, PHYS 3612 and MATH 2070.

PHYS 3112 Quantum Physics II (4 Credits)
Second of a two-quarter sequence. Angular momentum and spin; identical particles; the Pauli exclusion principle; atoms and solids: band theory; perturbation theory; the fine structure of hydrogen; the Zeeman effect; hyperfine splitting; the variational principle; the WKB approximation; tunneling; time dependent perturbation theory; emission and absorption of radiation. Scattering: partial wave analysis; the Born approximation. Prerequisite: PHYS 3111.

PHYS 3251 Astrophysics: Radiative Processes (4 Credits)
Because light is the primary means by which astronomers learn about the Universe, understanding the production and subsequent behavior of light is key to interpreting astronomical observations. This course introduces students to the physics of astrophysical radiation and its interaction with matter as it travels from its source to our detectors. Topics may include radiative transfer, emission and absorption processes, Compton processes, synchrotron radiation, thermodynamic equilibrium, radiative and collisional excitation, and spectroscopy of atoms and molecules. The course is aimed at advanced undergraduates, as well as graduate students focusing on astrophysics research. Prerequisites: PHYS 2252 and consent of instructor.

PHYS 3252 Astrophysics: Observations (4 Credits)
Astronomy is fundamentally an observational science and as such it is important for practitioners to understand how their data are collected and analyzed. This course is therefore a comprehensive review of current observational techniques and instruments, aimed at advanced undergraduates, as well as graduate students focusing on astrophysics research. This class introduces students to the capabilities and limitations of different types of instruments while exploring the sources and types of noise and providing statistical tools necessary for interpreting observational data. Prerequisites: PHYS 2252 and consent of instructor.

PHYS 3270 Workshop: Practical Astronomy (1-5 Credits)
Capstone coursework featuring studies in experimental, computational, and/or theoretical work in astronomy and astrophysics.

PHYS 3311 Advanced Laboratory I (1 Credit)
First of a three-quarter sequence. Advanced experimental techniques in physics. Meets with PHYS 2311. Prerequisite: instructor's permission.

PHYS 3312 Advanced Laboratory II (1 Credit)
Second of a three-quarter sequence. Advanced experimental techniques in physics. Meets with PHYS 2312. Prerequisite: instructor's permission.

PHYS 3313 Advanced Laboratory III (1 Credit)
Third of a three-quarter sequence. Advanced experimental techniques in physics. Meets with PHYS 2313. Prerequisite: instructor's permission.

PHYS 3510 Analytical Mechanics I (4 Credits)
Lagrangian and Hamiltonian mechanics. Prerequisites: PHYS 1113, PHYS 1213, or PHYS 1214 and MATH 2070 and consent of instructor.

PHYS 3520 Analytical Mechanics II (4 Credits)
Second of a two-quarter sequence: two-body central force problems, moving coordinate systems, rotational motion of rigid bodies, coupled oscillations and normal modes, and Hamiltonian mechanics. Prerequisite: PHYS 3510.

PHYS 3611 Electromagnetism I (4 Credits)
First of a two-quarter sequence. Vector algebra; differential vector calculus (gradient, divergence and curl); integral vector calculus (gradient, divergence and Stokes’ Theorems); line, surface and volume integrals; Electrostatics: the electric field, electric potential, work and energy in electrostatics; method of images, boundary value problems and solutions to Laplace’s equation in Cartesian, spherical and cylindrical coordinates; multipole expansion of the electric potential; electric fields in matter; polarization; the electric displacement vector; boundary conditions, linear dielectrics. Magnetostatics: magnetic fields and forces. Prerequisites: PHYS 1113, PHYS 1213, or PHYS 1214 and MATH 2070.

PHYS 3612 Electromagnetism II (4 Credits)
Second of a two-quarter sequence. Magnetic vector potential; magnetic fields in matter: magnetization; fields of magnetized objects; line and nonlinear magnetic materials; electromotive force, Ohm’s law; electromagnetic induction; Faraday’s law; Maxwell’s equations; the displacement current; boundary conditions; the Poynting theorem; momentum and energy density of the fields; the Maxwell stress tensor; the wave equation and electromagnetic waves in vacuum and matter; absorption and dispersion; wave guides; the potential formulation and gauge transformations; retarded potentials; dipole radiation. Prerequisite: PHYS 3611.

PHYS 3700 Advanced Topics: General (3 Credits)
Offered irregularly, depending on demand. May be taken more than once for credit. Prerequisite: instructor's permission.

PHYS 3711 Optics I (4 Credits)
First of a two-quarter sequence. Gaussian optics and ray tracing; matrix methods and application to optical design; elementary theory of aberrations; light as electromagnetic wave, diffraction and interference; interferometers and their applications. Elementary theory of coherence; selected topics. May include laboratory work as appropriate. Prerequisites: PHYS 1113, PHYS 1213 or PHYS 1214, and MATH 2070.

PHYS 3841 Thermal Physics I (4 Credits)
First of a two-quarter sequence. Laws of thermodynamics; thermal properties of gases and condensed matter; kinetic theory of gases, classical and quantum statistics. Prerequisites: PHYS 1113, PHYS 1213 or PHYS 1214 and MATH 2070.
Physics & Astronomy (PHYS)

PHYS 3991 Independent Study (1-8 Credits)
PHYS 3992 Directed Study (1-10 Credits)
PHYS 3995 Independent Research (1-10 Credits)