

Physics and Astronomy

Chair

- Philip E. Kaaret

Director, Undergraduate Studies

- Jane M. Nachtman

Director, Graduate Studies

- Vincent Rodgers

Director, Research Operations

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Undergraduate majors: physics (B.A., B.S.); applied physics (B.S.); astronomy (B.A., B.S.)

Undergraduate minors: physics; astronomy

Graduate degrees: M.S. in physics; M.S. in astronomy; Ph.D. in physics

Faculty: <https://physics.uiowa.edu/people>

Website: <https://physics.uiowa.edu/>

The Department of Physics and Astronomy provides comprehensive and rigorous instruction in all basic aspects of its subjects. It also provides research facilities and guidance in selected specialties for advanced individual scholarly work.

In addition to its undergraduate and graduate programs of study, the department offers several courses that undergraduate students in all majors may use to satisfy the GE CLAS Core Natural Sciences requirement. Look for courses with prefixes ASTR and PHYS under "Natural Sciences" in the GE CLAS Core section of the Catalog. The department often offers First-Year Seminars designed for entering undergraduates.

The department also participates in an interdisciplinary doctoral program, the Program in Applied Mathematical and Computational Sciences (Graduate College).

All of the department's courses and advanced laboratories are taught by faculty members. Faculty members also supervise associated laboratories taught by graduate students. Enrollment in courses beyond the elementary level is typically 15 to 20 students; there is ample opportunity for individual work. Special introductory courses are offered for students majoring in physics and astronomy and for others with a special interest in these subjects.

Total enrollment in physics and astronomy courses is approximately 2,200 each semester of the academic year and 150 during the summer session. The department has around 120 undergraduate majors, half of whom are honors students, and 75 graduate students.

Programs

Undergraduate Programs of Study

Majors

- Major in Physics (Bachelor of Arts)
- Major in Astronomy (Bachelor of Arts)
- Major in Physics (Bachelor of Science)

- Major in Applied Physics (Bachelor of Science)
- Major in Astronomy (Bachelor of Science)

Minors

- Minor in Physics
- Minor in Astronomy

Graduate Programs of Study

Majors

- Master of Science in Physics
- Master of Science in Astronomy
- Doctor of Philosophy in Physics

Facilities

The department has a number of well-equipped laboratories and observatories. Faculty, students, and staff access national supercomputers via the internet, and have access to high performance computing clusters on campus. The central machine shop is fully equipped and staffed by skilled instrument makers and machinists, and there are electronics and machine shops for use by advanced students and research staff.

Experimental research is conducted in astronomy (optical, radio, and X-ray), atomic and molecular physics, condensed matter physics, elementary particle physics, laser physics, medical physics, plasma physics, and space physics. Extensive facilities are available for construction of specialized research equipment and for data processing and analysis.

State-of-the-art semiconductor materials and devices are grown in two molecular beam epitaxy machines. Ultrafast laser techniques are developed and used to probe electron transport, energy relaxation, recombination, and spin dynamics in the novel nanostructures grown in these machines. Experiments also are conducted on laser-induced coherent phenomena and coherent control of charge carriers in semiconductor nanostructures. The experimental condensed matter program is closely coordinated with the condensed matter theory group.

Plasma physics is an active area of experimental and theoretical research. Laboratory experiments studying plasma processes of importance in various space and astrophysical plasmas are performed in a Q machine, including experiments on waves and instabilities in dusty plasmas. Additional laboratory and microgravity experiments with dusty plasmas include studies of Coulomb crystals, shocks, and complex fluids. Glow discharges for plasma processing applications are studied using laser diagnostics and numerical simulations. Wave propagation and plasma particle dynamics also are studied in collisionless plasmas through laboratory experiments. Laser techniques are developed for measuring plasma flow and following particle orbits. Plasma theory efforts include analytical and numerical investigations of magnetic reconnection and turbulence in space and astrophysical plasmas; collaboration with laboratory and space plasma experimental groups in strongly coupled dusty plasmas, waves, and instabilities; and free electron lasers and hydrodynamic turbulence.

State-of-the-art laser systems are available for high-resolution spectroscopic measurement and ultrafast studies of molecular structure, for collisional relaxation and nonlinear optical effects in atomic and molecular systems, and for plasma diagnostics.

Experimental research in elementary particle physics is carried out at Fermi National Accelerator Laboratory, Stanford Linear Accelerator Center, CERN in Switzerland, and other international laboratories. The present generation of high-energy experiments has been designed to probe both the strong nuclear force and the weak interactions.

The department is well-equipped for research and instruction in observational astronomy. The primary optical instrument is a fully automated 15-inch telescope at a dark-sky site in Arizona. The telescope is equipped with CCD cameras and a variety of filters. There are 3-meter and 4.5-meter radio telescopes on the roof of Van Allen Hall, which are used for instruction and student research projects.

Research programs in galactic and extragalactic radio astronomy are carried out using the facilities of the National Radio Astronomy Observatory, including the Very Large Array and the Very Long Baseline Array, one element of which is 10 miles north of campus. Current long-term research activities include studies of the center of the Milky Way galaxy; investigations of extragalactic radio sources; the formation of powerful winds in young, luminous stars; radio-wave scattering in the interstellar and interplanetary media; and interacting binary stars. There is a research program in X-ray astronomy and a laboratory for instrument development. Research topics in X-ray astronomy concentrate on observations of X-ray emission from black holes and supernova remnants, using existing spacecraft.

Active theoretical research is carried on in astrophysics; atomic, molecular, and optical physics; condensed matter physics; elementary particle physics; laser physics; mathematical physics; nuclear physics; plasma physics; and space physics. An active mathematical physics seminar fosters the exchange of ideas between mathematics and physics.

The primary emphasis of Iowa's program in experimental and theoretical space physics is on studies of cosmic and heliospheric physics, magnetospheric physics, and magnetosphere-ionosphere interactions. Facilities are available for designing and constructing spacecraft instruments. Investigators in the department have flown instruments for studying plasmas, energetic charged particles, auroral images, plasma waves, and radio emissions on a wide variety of terrestrial and planetary spacecraft, including Pioneer 10 and 11, Dynamics Explorer, Voyager 1 and 2, Galileo, Polar, Cassini, and Mars Express.

Courses

- Physics Courses [p. 2]
- Astronomy Courses [p. 5]

Physics Courses

- PHYS:1000 First-Year Seminar** **1 s.h.**
Small discussion class taught by a faculty member; topics chosen by instructor; may include outside activities (e.g., films, lectures, performances, readings, visits to research facilities). Requirements: first- or second-semester standing.
- PHYS:1200 Physics of Everyday Experience** **3 s.h.**
Principles of physics; basic motion, behavior of fluids, waves, temperature and heat, gravity and planetary motion, electricity and magnetism, optics, nuclear energy, radioactivity, and medical imaging technology; examples from everyday experience; for non-science majors. GE: Natural Sciences without Lab.

PHYS:1400 Basic Physics **3-4 s.h.**
Quantitative treatment of mechanics, electricity, heat, liquids, gases, and atomic, nuclear, and elementary particle physics. Requirements: must have completed high school trigonometry or achieved a minimum ALEKS score of 75%. GE: Natural Sciences with Lab; Natural Sciences without Lab.

PHYS:1409 Basic Physics Lab **1 s.h.**
Laboratory for PHYS:1400. Corequisites: PHYS:1400 (if not taken as a prerequisite). GE: Natural Sciences Lab only.

PHYS:1410 Physics of Sound **3-4 s.h.**
Acoustical foundations of music; production of sound by vibrating objects, properties of sound waves, vocal acoustics, hearing, room acoustics, principles of electroacoustics. GE: Natural Sciences with Lab; Natural Sciences without Lab.

PHYS:1511 College Physics I **4 s.h.**
Algebra-based treatment of mechanics, waves, thermodynamics, and special relativity. Requirements: must have completed high school trigonometry or achieved a minimum ALEKS score of 75%. GE: Natural Sciences with Lab.

PHYS:1512 College Physics II **4 s.h.**
Continuation of PHYS:1511; algebra-based treatment of electricity, magnetism, light, and modern physics. Prerequisites: PHYS:1611 or PHYS:1511. GE: Natural Sciences with Lab.

PHYS:1611 Introductory Physics I **4 s.h.**
Calculus-based treatment of mechanics, waves, and thermodynamics. Corequisites: MATH:1550 or MATH:1850. GE: Natural Sciences with Lab.

PHYS:1612 Introductory Physics II **3-4 s.h.**
Continuation of PHYS:1611; calculus-based treatment of electricity, magnetism, and light. Prerequisites: PHYS:1611. Corequisites: MATH:1560 or MATH:1860. GE: Natural Sciences with Lab; Natural Sciences without Lab.

PHYS:1619 Introductory Physics II Lab **1 s.h.**
Laboratory for PHYS:1612. Requirements: 3 s.h. in PHYS:1612. GE: Natural Sciences Lab only.

PHYS:1701 Physics I **4 s.h.**
Introduction to physics; calculus-based treatment of Newtonian mechanics for point particles and rigid bodies; conservation laws. Offered fall semesters. Corequisites: MATH:1850. Requirements: physics or astronomy major. GE: Natural Sciences with Lab.

PHYS:1702 Physics II **4 s.h.**
Continuation of PHYS:1701; introduction to fluid mechanics, electricity, magnetism (Maxwell's equations). Offered spring semesters. Prerequisites: PHYS:1701. Corequisites: MATH:1860. Requirements: physics or astronomy major. GE: Natural Sciences with Lab.

PHYS:1999 Undergraduate Seminar **arr.**
Selected topics in physics and astronomy; discussion, presentations.

PHYS:2703 Physics III **4 s.h.**
Continuation of PHYS:1702; introduction to physics; calculus-based treatment of electromagnetic waves and optics; mechanical and sound waves; thermal physics. Offered fall semesters. Prerequisites: PHYS:1702.

PHYS:2704 Physics IV **3-4 s.h.**
Introduction to quantum mechanics and other topics in modern physics, including special relativity, atomic and solid state physics. Offered spring semesters. Prerequisites: (PHYS:1612 or PHYS:2703) and (MATH:1860 or MATH:1550). Requirements: for 3 s.h. option—nonmajor.

- PHYS:2905 Programming for Physics** 2 s.h.
Introduction to scientific programming for applications in physics.
- PHYS:2990 Reading in Physics** arr.
Selected topics in physics.
- PHYS:3500 Undergraduate Practicum** arr.
Experiences that provide special opportunities for students to gain practical and hands-on training related to topics in physics; practicums typically arranged by individual faculty members. Requirements: application and acceptance into practicum.
- PHYS:3710 Intermediate Mechanics** 3 s.h.
Introduction to Newtonian mechanics; noninertial reference systems; central forces, celestial mechanics; rigid body motion; Lagrangian and Hamiltonian equations of motion; small oscillations. Prerequisites: (PHYS:1611 or PHYS:1511 or PHYS:1701) and (MATH:1860 or MATH:1560).
- PHYS:3730 Statistical Physics** 3 s.h.
Integrated introduction to subjects of thermodynamics, statistical mechanics, classical and quantum statistics of interacting particles; kinetic theory; emphasis on applications. Prerequisites: PHYS:2704.
- PHYS:3741 Introduction to Quantum Mechanics I** 3 s.h.
Superposition principle, Stern-Gerlach experiment, linear operators, measurement theory, time evolution, angular momentum, wave mechanics in one dimension, one-dimensional harmonic oscillator, two-body problems with central forces, and the hydrogen atom. Prerequisites: MATH:2850 and PHYS:2704 and MATH:2700.
- PHYS:3742 Introduction to Quantum Mechanics II** 3 s.h.
Continuation of PHYS:3741; Perturbation theory, variational methods, WKB approximation, scattering, Helium atom, periodic table, atomic spectroscopy, transition rates, and other selected applications. Prerequisites: PHYS:3741.
- PHYS:3750 Fundamentals of Micro and Nanofabrication** 3 s.h.
Fundamentals of micro and nanofabrication processes; physical principles of photo and electron beam lithography, alternative nanolithography techniques, thin film deposition, molecular beam epitaxy, atomic layer deposition, self-assembly; metrology methods; physical and chemical processes of wet and plasma etching; clean room science, operations, safety protocols; sequential micro and nanofabrication processes involved in manufacture of semiconductor, photonic, nanoscale devices; imaging and characterization of micro and nanostructures; scientific and technological applications of emerging micro and nanodevices and systems. Prerequisites: BIOL:1141 or CHEM:1120 or PHYS:1612 or CHEM:1110 or CHEM:1060 or PHYS:1702 or PHYS:1611. Requirements: undergraduate lab course in chemistry, biology, physics, or engineering.
- PHYS:3756 Intermediate Laboratory** 3 s.h.
Introduction to instruments and techniques of experimental physics and basic skills needed for carrying out experimental physics research; hands-on use of a variety of instruments and equipment. Prerequisites: PHYS:2704. Corequisites: PHYS:3811.
- PHYS:3811 Electricity and Magnetism I** 3 s.h.
Introduction to electricity and magnetism; topics include electrostatics, magnetostatics, potential theory, and electric and magnetic fields in matter. Prerequisites: (MATH:3550 or MATH:2850) and (PHYS:1612 or PHYS:1702 or PHYS:1512).
- PHYS:3812 Electricity and Magnetism II** 3 s.h.
Continuation of PHYS:3811; introduction to electricity and magnetism; topics include Maxwell's equations, electrodynamics, electromagnetic waves, radiation, and special relativity. Prerequisites: PHYS:3811.
- PHYS:3850 Electronics** 4 s.h.
Design and construction of small circuits; use of measurement instruments—oscilloscope, multimeter, function generator; circuits, including transistors, operational amplifiers, digital, analog-to-digital conversion. Prerequisites: PHYS:1512 or PHYS:1612 or PHYS:1702. Requirements: physics or astronomy major.
- PHYS:4720 Introductory Optics** 3 s.h.
Wave motion and superposition, electromagnetic theory, photons, propagation of light, geometrical and physical optics, interference, diffraction, polarization, and Fourier optics; optical components, devices, and systems. Prerequisites: (PHYS:1512 or PHYS:2703 or PHYS:1612) and (MATH:1560 or MATH:1860). Same as ECE:4720.
- PHYS:4726 Electro Optics** 3 s.h.
Wave equation solutions; optical birefringence; finite beam propagation in free space, dielectric waveguides and fibers; optical resonators; nonlinear phenomena; electro-optic, acousto-optic modulation; optical detection, noise; application to communication systems. Requirements: for ECE:5790—ECE:3700; for PHYS:4726—PHYS:3812. Same as ECE:5790.
- PHYS:4728 Introductory Solid State Physics** 3 s.h.
Phenomena associated with solid state; classification of solids and crystal structures, electronic and vibrational properties in solids; thermal, optical, magnetic, dielectric properties of solids. Prerequisites: PHYS:3741. Same as ECE:4728.
- PHYS:4731 Plasma Physics I** 3 s.h.
Physics of ionized gases, including orbit theory, guiding center motion, adiabatic invariants, ionization balance description of plasmas by fluid variables and distribution functions; linearized wave motions, instabilities; magnetohydrodynamics. Prerequisites: PHYS:3812.
- PHYS:4740 Elementary Particles and Nuclear Physics** 3 s.h.
Accelerators, particle detectors, passage of radiation through matter; nuclear structure, nuclear reactions; quark model of hadrons; strong, electromagnetic, weak interactions of elementary particles; gauge theories, intermediate vector bosons; unification of electromagnetic and weak interactions. Prerequisites: PHYS:3741.
- PHYS:4750 Advanced Laboratory** 3 s.h.
Advanced experimental work and development of new experiments. Prerequisites: PHYS:3756.
- PHYS:4761 Mathematical Methods of Physics I** 3 s.h.
Functions of complex variables, integration methods, linear vector spaces, tensors, matrix algebra. Prerequisites: MATH:2850.
- PHYS:4762 Mathematical Methods of Physics II** 3 s.h.
Continuation of PHYS:4761; Hilbert space, special functions, Fourier transform and expansions in orthogonal polynomials, differential equations, Green's functions. Prerequisites: PHYS:4761.

- PHYS:4820 Optical Signal Processing** 3 s.h.
Linear systems description of optical propagation; diffraction and angular plane wave spectrum; lenses as Fourier transformers, lens configurations as generalized optical processors; lasers, coherence, spatial frequency analysis; holography; convolvers, correlators, matched filters; synthetic aperture radar; optical computing. Requirements: for ECE:5780—ECE:3700; for PHYS:4820—PHYS:3812. Same as ECE:5780.
- PHYS:4860 Computational Physics** 3 s.h.
Introduction to contemporary use of computers by physicists; topics such as numerical solutions of ordinary differential equations in classical mechanics, boundary value problems in electricity and magnetism, eigenvalue problems in quantum mechanics, Monte Carlo simulations in statistical mechanics, methods of data analysis. Prerequisites: PHYS:3741 and PHYS:3811 and PHYS:3710.
- PHYS:4905 Special Topics in Physics** arr.
Introduction to scientific programming using the Python language and linear algebra for applications in physics.
- PHYS:4990 Reading in Physics** arr.
Selected topics in physics.
- PHYS:4999 Undergraduate Research** arr.
Supervised research leading to written report or oral presentation.
- PHYS:5000 Workshops and Special Training in Physics** arr.
Workshops and special training opportunities for postbaccalaureate students; may include collaborations with other departments, institutions, or externally funded research organizations.
- PHYS:5710 Classical Mechanics** 3 s.h.
Dynamics of mass points; Lagrange multipliers, small oscillations, Hamilton's equations; canonical transformations, Hamilton-Jacobi theory; chaos. Prerequisites: PHYS:3710.
- PHYS:5730 Statistical Mechanics I** 3 s.h.
Probability concepts; kinetic equations; classical and quantum equilibrium statistical mechanics with applications, including ideal and imperfect gases and phase transitions, irreversible processes, fluctuation-dissipation theorems. Prerequisites: PHYS:3730 and PHYS:3741.
- PHYS:5741 Quantum Mechanics I** 3 s.h.
Nonrelativistic quantum mechanics, Schrödinger wave mechanics, Hilbert space methods, perturbation theory, scattering, spin and angular momentum, identical particles, selected applications, introduction to relativistic theory. Prerequisites: PHYS:3741 and PHYS:3742.
- PHYS:5742 Quantum Mechanics II** 3 s.h.
Continuation of PHYS:5741. Prerequisites: PHYS:5741.
- PHYS:5811 Classical Electrodynamics I** 3 s.h.
Advanced electrostatics, boundary value problems, Green's functions, Maxwell's equations, radiation theory, physical optics, multipole expansion of radiation field.
- PHYS:5812 Classical Electrodynamics II** 3 s.h.
Special relativity, motion of charges in fields, theories of radiation reaction, special topics. Prerequisites: PHYS:5811.
- PHYS:5905 Special Topics in Physics** 3 s.h.
Selected topics in physics.
- PHYS:6723 Advanced Optics** 3 s.h.
Classical theory of absorption and emission; laser theory, threshold, rate equations, saturation, spectral and spatial hole burning; resonators and Gaussian beam optics; dispersion and light scattering; nonlinear optics, three- and four-wave mixing, harmonic generation, parametric amplification, and stimulated scattering. Prerequisites: PHYS:3812.
- PHYS:7270 Ethics in Physics for Graduate Students** arr.
Responsible conduct and ethics training.
- PHYS:7604 Ethics in Physics for Postdocs** 0 s.h.
Responsible conduct and ethics training.
- PHYS:7720 Semiconductor Physics** 3 s.h.
Electronic, optical, and materials properties of semiconductors. Prerequisites: PHYS:4728 and PHYS:5742. Same as ECE:7720.
- PHYS:7722 Advanced Condensed Matter** 3 s.h.
Elementary excitations, plasmonics, exchange/magnetism, hyperfine interactions, resonance, superconductivity, topological materials. Prerequisites: PHYS:7720.
- PHYS:7729 Plasma Physics II** 3 s.h.
Continuation of PHYS:4731; cold plasma waves, MHD stability, kinetic theory of plasmas, including Landau damping and velocity space instabilities; nonlinear evolution. Prerequisites: PHYS:4731.
- PHYS:7730 Advanced Plasma Physics I** 3 s.h.
Microscopic plasma behavior: statistical mechanics of plasmas; Liouville equation; BBGKY hierarchy; Fokker-Planck equation and relaxation processes; Balescu-Lenard equation; Vlasov equation and linearized wave motion; shocks, nonlinear plasma motions, and instabilities; fluctuations and radiation processes; topics from recent literature.
- PHYS:7740 Introduction to Quantum Field Theory** 3 s.h.
Quantization of relativistic and nonrelativistic field theories, covariant perturbation theory, theory of renormalization, dimensional regularization, renormalization group theory, introduction to gauge theories and anomalies. Prerequisites: PHYS:5742.
- PHYS:7746 Particle Physics** 3 s.h.
Elementary particle properties and phenomenology, quark-parton models, quantum chromodynamics, unified theory of weak and electromagnetic interactions.
- PHYS:7760 General Relativity** 2-3 s.h.
Einstein's theory of gravitation; principles of general relativity.
- PHYS:7761 Cosmology** 3 s.h.
Einstein's theory of general relativity radically changed the way we understand the cosmos by providing a mathematical description of space-time itself—this is cosmology; the last three decades have shown remarkable evidence that cosmology is an experimentally testable theory; students explore mathematical underpinnings of cosmology by studying the early universe, the cosmic microwave background, inflation, big bang nucleosynthesis, neutrino physics, quantum field theory effects on space-time, and other issues. Prerequisites: PHYS:7760.
- PHYS:7840 Quantum Gauge Theories** 3 s.h.
Gauge invariance, introductory group theory, Yang-Mills theories, electroweak theory, quantum chromodynamics, running coupling constants, operator product expansions, Ward identities, spontaneous symmetry breaking, chiral anomalies, instantons, monopoles, effective Lagrangians, supersymmetry, quantum gravity, introduction to string theory. Prerequisites: PHYS:7740.
- PHYS:7905 Special Topics in Physics** arr.

PHYS:7920 Seminar: Solid State Physics

Current research.

PHYS:7930 Seminar: Plasma Physics

Current research. Same as ECE:7930.

PHYS:7936 Seminar: Space Physics

Current research.

PHYS:7945 Seminar: Math/Physics

Current research.

PHYS:7946 Seminar: Nuclear and Particle Physics

Current research.

PHYS:7990 Research: Physics**PHYS:7992 Individual Critical Study**

Essay on topic chosen in consultation with faculty member.

Requirements: candidacy for M.S. with critical essay.

Astronomy Courses

ASTR:1000 First-Year Seminar**1 s.h.**

Small discussion class taught by a faculty member; topics chosen by instructor; may include outside activities (e.g., films, lectures, performances, readings, visits to research facilities).

ASTR:1060 Big Ideas: Origins of the Universe, Earth, and Life**3 s.h.**

Origin of the universe, the biochemistry of life, and the origin of life on Earth; for non-science majors. Recommendations: first-year or sophomore standing. GE: Natural Sciences without Lab. Same as BIOL:1060, EES:1060.

ASTR:1070 Stars, Galaxies, and the Universe**3-4 s.h.**

Students survey topics including the Sun; life cycles of stars including black holes and pulsars; diversity of galaxies including the Milky Way and distant quasars; cosmology—the history, structure, and fate of the universe; current results from recent astronomical observations; for non-science majors. Recommendations: closed to physics and astronomy majors. GE: Natural Sciences with Lab; Natural Sciences without Lab.

ASTR:1079 Introductory Astronomy Laboratory**1 s.h.**

Laboratory for ASTR:1070. GE: Natural Sciences Lab only.

ASTR:1080 Exploration of the Solar System**3-4 s.h.**

Survey of the solar system; topics include physical properties of the planets, comets, and asteroids; origin of the solar system; search for extrasolar planetary systems; search for life in the universe; current results of recent planetary space missions; night sky observation; for non-science majors. Recommendations: closed to physics and astronomy majors. GE: Natural Sciences with Lab; Natural Sciences without Lab.

ASTR:1085 Citizen Astronomy**3 s.h.**

Survey of topics in astronomy and astrophysics; topics include the Solar System and exoplanets, nearby stars in the Galaxy, distant galaxies and unseen black holes; focus on citizen science projects that allow students to examine real data; for non-science majors. GE: Natural Sciences without Lab.

ASTR:1091 Life in the Universe**3 s.h.**

Are we alone? Scientific foundations of this question, technology behind searches for extraterrestrial life in the solar system and on extrasolar planets; evolution of life on Earth, likelihood that such conditions exist elsewhere in the universe; cultural consequences of discovering extraterrestrial life. GE: Natural Sciences without Lab.

ASTR:1771 Introductory Astronomy I: Basic Astrophysics and Planetary Astronomy**4 s.h.****arr.**

Quantitative introduction to physical principles needed to understand astronomical phenomena (e.g., laws of motion, gravitation, radiation), astronomical instrumentation, properties structure, and evolution of solar system bodies, exoplanets, and the search for life. Requirements: four years of high school math. GE: Natural Sciences with Lab.

arr.**arr.****ASTR:1772 Introductory Astronomy II: Stellar, Galactic, and Extragalactic Astronomy****4 s.h.****arr.****arr.****arr.**

Continuation of ASTR:1771; quantitative introduction to stellar, Galactic, and extragalactic astronomy; topics include the Sun, stellar evolution, stellar corpses such as neutron stars and black holes, the Milky Way galaxy, the interstellar medium, galaxies, cosmology, and fate of the universe. Requirements: four years of high school math. GE: Natural Sciences with Lab.

ASTR:2991 Reading in Astronomy**arr.**

Selected topics in astronomy.

ASTR:3500 Undergraduate Practicum**arr.**

Undergraduate practicum experiences that provide special opportunities for students to gain practical and hands-on training related to topics in astronomy; practicums typically arranged by individual faculty members. Requirements: application and acceptance into practicum.

ASTR:3771 Introduction to Astrophysics I**3 s.h.**

Topics include celestial mechanics, radiative transfer, stellar structure and evolution, and star formation; first in a two-semester sequence. Prerequisites: PHYS:2704 and ASTR:1772 and ASTR:1771 and (MATH:2850 or MATH:3550) and (MATH:2700 or MATH:2550). Recommendations: computer programming experience.

ASTR:3772 Introduction to Astrophysics II**3 s.h.**

Continuation of ASTR:3771; topics include post-main-sequence stellar evolution, stellar remnants, close binary stars, the Milky Way and other galaxies, active galactic nuclei, galaxy evolution, and cosmology; second in a two-semester sequence. Prerequisites: ASTR:3771.

ASTR:4770 Radio Astronomy**3 s.h.**

Survey of radio astronomy, emphasizing technical aspects; radiation, antennas, receivers, radio spectroscopy, interferometer arrays and aperture synthesis; emission mechanisms, pulsars, supernova remnants, radio galaxies.

ASTR:4850 Astronomical Laboratory**3 s.h.**

Introduction to instruments of optical (and sometimes multi-wavelength) astronomy and basic skills needed for carrying out observational astronomical research; hands-on use of observing equipment; nighttime observing sessions. Prerequisites: PHYS:2704 and ASTR:1772 and ASTR:1771.

ASTR:4996 Reading in Astronomy**arr.****ASTR:6782 Extragalactic Astronomy****3 s.h.**

Normal and active galaxies, large scale structure, the early Universe, cosmology.

ASTR:6785 The Interstellar Medium**3 s.h.**

The interstellar medium; optical properties of small interstellar grains, radiative processes in interstellar gas, structure of HII regions, interstellar shock waves, supernova remnants, modification of interstellar medium by luminous stars, molecular clouds.

ASTR:6790 Stellar Astrophysics**3 s.h.**

Stellar interiors, nuclear astrophysics; advanced topics.

ASTR:6870 Radiative Processes in Astrophysics 3 s.h.

Physics of stars including interiors, spectra, nuclear processes, plasma hydrodynamics, and the extreme physics of condensed final states.

ASTR:6880 High Energy Astrophysics 3 s.h.

Detection of X-rays and gamma-rays, black holes and neutron stars, accretion onto compact objects, pulsars, supernova remnants, cosmic rays, and gamma-ray bursts.

ASTR:7775 Special Topics in Astrophysics 1-3 s.h.

Advanced lectures.

ASTR:7830 Space and Astrophysical Plasma Physics 3 s.h.

Dynamics and evolution of space and astrophysical plasmas; heliosphere, planetary magnetospheres, accretion disks; plasma waves, shock waves, turbulence.

ASTR:7970 Seminar: Astrophysics arr.

Current research.

ASTR:7991 Research: Astronomy arr.

Original research in observational, theoretical astronomy.