Department of Physics and Astronomy

Why study physics and astronomy?

Our goal is to understand the physical universe. The questions addressed by our department's research and education missions range from the applied, such as an improved understanding of the materials that can be used for solar cell energy production, to foundational questions about the nature of mass and space, and how the Universe was formed and subsequently evolved, and how astrophysical phenomena affected the Earth and its evolution. We study the properties of systems ranging in size from smaller than an atom to larger than a galaxy on timescales ranging from billionths of a second to the age of the universe. Our courses and laboratory/research experiences help students hone their problem solving and analytical skills and thereby become broadly trained critical thinkers. While about half of our majors move on to graduate studies in STEM, many find employment in the private sector in diverse careers ranging from financial analysts to physicians. Graduates of all our degree programs can be found in key positions regionally, nationally, and internationally. In this way, our department is at the forefront of telling the academic story of the University of Kansas to people around the state and around the world.

Undergraduate Programs

We welcome all students curious about the universe around them. This includes not only students planning on graduate study in STEM, but also students from other disciplines where a background in foundational physical science and critical thinking can be useful – example teaching and medicine – and anyone seeking to include astronomy and physics as part of their general education. The department offers BS degrees in astronomy, physics, and engineering physics and BA degrees in astronomy and physics. Degrees in astronomy and physics are granted through the College of Liberal Arts and Sciences whereas engineering physics degrees are granted through the School of Engineering. The primary degree offered is a BS in Physics. In addition to this standard BS in Physics, there are also interdisciplinary and pre-medicine versions (specializations) of the BS in Physics degree. The interdisciplinary track allows students to take elective courses in other STEM disciplines and the pre-medicine emphasis is for students interested in health professions. We also offer minors in astronomy and physics and a certificate in astrophysics of origins. We involve our undergraduate majors in cutting-edge research practically from the day they join the department; research is a requirement of both the BS Astronomy and BS Physics degrees. The breadth of our research program affords our students exposure to a number of different fields and we are justifiably proud of our undergraduate researchers who routinely publish papers, attend conferences, and/or conduct research abroad (in locales such as Antarctica, Chile, and CERN).

Courses for Nonmajors

ASTR 191 is a survey of contemporary astronomy, taught at a level using basic mathematics; ASTR 391 offers an introduction to physical astronomy at a calculus-based level. The department offers two introductory physics sequences that include laboratory work. PHSX 114 and PHSX 115 cover the major fields of physics without calculus. PHSX 211 and PHSX 212, with labs PHSX 216 and PHSX 236, provide a calculus-based foundation in physics for students in physical science, engineering, and mathematics. PHSX 313 and the laboratory course, PHSX 316, provide an introduction to modern physics for majors in physics and some engineering and physical science programs.

Students in biological sciences, health sciences, physical sciences, mathematics, engineering, and prospective elementary and secondary teachers should see appropriate sections of this catalog and major advisors for guidance about required physics course work. Chemistry majors should note that PHSX 211 and PHSX 212 are prerequisites to advanced work in chemistry.

For programs in engineering physics (https://catalog.ku.edu/engineering/), see the School of Engineering section of the online catalog.

Graduate Programs

The department offers two primary graduate programs: (i) an M.S. degree in Physics and (ii) a Ph.D. degree in Physics. The M.S. in Physics has the possibility of having a concentration in Computational Physics and Astronomy. This option requires a thesis, as does one of the M.S.-Physics options. The department does not offer a graduate-level degree in Astronomy, although students have obtained M.S. degrees in Physics by doing astronomy projects. In addition, the department has added flexibility in its course offerings to allow a student to obtain a Ph.D. in Physics while working on an astronomy or astrophysics multidisciplinary plan of study.

The department is proud to be an APS Bridge Program (https://physics.ku.edu/graduate-program/bridge-program/) partner. Information about admission, requirements, and graduate programs is also on the Department of Physics & Astronomy web page (https://physics.ku.edu/graduate-program/). Please note that the General and Subject GRE are not required for admissions to the Physics and Astronomy graduate program.

Courses

ASTR 150. Seminar in Physics, Astronomy and Engineering Physics. 0.5 Credits.
This course is intended for all students in physics, astronomy, and engineering physics. Course content includes topics of current interest in all fields of physics and astronomy and an introduction to professional ethics and frameworks for ethical decision making. Topics covered include but are not limited to nanotechnology, cosmology, nuclear and high energy physics, galactic evolution, condensed matter physics, space physics, biophysics, and plasma physics. Course will include hands on demonstrations, group in-class activities and general advising information. (Same as PHSX 150.)

ASTR 177. First Year Seminar: _____. 3 Credits. GE11 GLBC
A limited-enrollment, seminar course for first-time freshmen, addressing current issues in Astronomy. Course is designed to meet the critical thinking learning outcome of the KU Core. First-Year Seminar topics are coordinated and approved by the Office of Academic Programs and Experiential Learning. Prerequisite: Open to Freshmen only (less than 30 hours).

ASTR 191. Contemporary Astronomy. 3 Credits. GE3N SWT NLEC

The structure and evolution of the universe, from nearby planets to distant quasars, is examined. Topics include recent discoveries concerning planets, stars, pulsars and black holes as well as their evolution, the structure of the universe today and how it will be in the future. The emphasis is descriptive rather than mathematical. (Same as PHSX 191.) Prerequisite: Eligibility for MATH 101.

ASTR 196. Contemporary Astronomy Laboratory. 1 Credits. LFE NLAB
An introduction to astronomical observations and modern data analysis methods. Students will carry out independent investigations as well as standard exercises. This is a hybrid course, delivered through Canvas and in person. (Same as PHSX 196.) Prerequisite: Corequisite: ASTR 191 or PHSX 191.

ASTR 390. Undergraduate Problems. 1-3 Credits. AE61 CAP
Undergraduate observational or theoretical problems in astronomy. Maximum credit, six hours. Prerequisite: Permission of instructor or academic advisor.

ASTR 391. Physical Astronomy, Honors. 3 Credits. GE3N
An honors, calculus-based introduction to astronomy and astrophysics, required for astronomy majors. Components of the Universe - from planetary systems, stellar systems, large scale structure and cosmology - are examined to illuminate the physics principles which govern their evolution. Prerequisite: MATH 125.

ASTR 394. The Quest for Extraterrestrial Life. 3 Credits. GE11
An introduction to the search for planets around other stars and for life in the universe beyond the earth. A discussion of the astronomical conditions under which life might form and the biological conditions of life formation and evolution. Methods of searching for extraterrestrial life will also be discussed. Prerequisite: An introductory course in astronomy, biology, or geology.

ASTR 501. Honors Research. 1-4 Credits. AE61 CAP
This course is for students seeking Departmental Honors in Astronomy, Engineering Physics, or Physics to fulfill the undergraduate research requirement. At the completion of the required four hours of total enrollment, a written and oral report of the research is required. (Same as EPHX 501 and PHSX 501.) Prerequisite: Junior/Senior standing in Astronomy, Engineering Physics, or Physics, or permission of instructor.

ASTR 503. Undergraduate Research. 1-4 Credits. AE61 CAP
This course is for students seeking to fulfill the undergraduate research requirement. Students are expected to participate in some area of ongoing research in the department, chosen with the help of their advisor. At the end of the term, students will present their results in a seminar to other students and faculty. (Same as EPHX 503 and PHSX 503.) Prerequisite: Junior/Senior standing in Astronomy, Engineering Physics, or Physics, or permission of instructor.

ASTR 591. Stellar Astronomy. 3 Credits.
Fundamentals of stellar astronomy including astronomical optics and techniques, coordinate and time systems, stellar spectroscopy, properties of normal, binary, and variable stars. Prerequisite: ASTR 391 and PHSX 211 or PHSX 210 or PHSX 213.

ASTR 592. Galactic and Extragalactic Astronomy. 3 Credits.
A study of stellar groups, the interstellar medium, galactic structure and dynamics, galaxies, and cosmology. Prerequisite: ASTR 391 and ASTR 591 or consent of instructor.

ASTR 596. Observational Astrophysics. 4 Credits. AE61 CAP
Students will acquire practical experience with astronomical equipment and as well as with data reduction techniques used in research and educational contexts. ASTR 596, combined with an independent research experience, provides a pathway for students to demonstrate creativity and the integration of background knowledge. Prerequisite: ASTR 391 and ASTR 591 and EECS 138 or EECS 168 or EECS 169 or PHSX 315.

ASTR 691. Astrophysics I. 3 Credits.
An introduction to radiation processes, thermal processes, and radiative transfer in stellar atmospheres and the interstellar medium. (Same as EPHX 691 and PHSX 691.) Prerequisite: PHSX 313 and ASTR 391.

ASTR 692. Astrophysics II. 3 Credits.
The formation and evolution of stars, nucleosynthesis of the elements, and the physical processes of high energy physics. Prerequisite: PHSX 313, ASTR 391, and ASTR 691 or consent of instructor.

ASTR 791. Seminar in Astrophysics. 1 Credits.
Seminar designed to cover current topics in the physics of the Universe beyond the solar system. The content will vary. Graduate students engaged in or preparing for research may repeat enrollments in this course. Open to undergraduates with twelve hours of physics/astronomy courses numbered 500 or above, or consent of instructor.

ASTR 792. Topics in Advanced Astrophysics. 3 Credits.
This course will address one or more of the following advanced topics in astrophysics: high energy astrophysics, nuclear astrophysics, galactic and extragalactic astrophysics, space physics, cosmology, astro-bioyphysics, and the interstellar and intergalactic media (ISM/IGM.) This course may be repeated for credit if topical content differs. (Same as PHSX 792.) Prerequisite: ASTR 692 or permission of instructor.

ASTR 794. Interiors and Atmospheres. 3 Credits.
This course covers energy generation, flow, hydrostatic equilibrium, equation of state in stars and exoplanets, including the dependence of stellar parameters (central surface temperature, radius, luminosity, etc.) on stellar mass and its relation to physical constants. Other topics may include the relationship of these parameters to stellar evolution; stellar and exoplanet interiors, opacity sources, radiative and convective energy flow; nuclear reactions in stars; and the atmospheric structure of exoplanets. (Same as PHSX 794.) Prerequisite: ASTR 692 or permission of instructor.

ASTR 795. Space Plasma Physics. 3 Credits.
The physics of fully ionized gases in magnetic fields and their application to interplanetary processes, planetary radiation belts, and the surface of the sun. The motion of charged particles in magnetic fields, magnetohydrodynamic waves, the solar wind and the magnetosphere. (Same as PHSX 795.) Prerequisite: PHSX 621. Corequisite: PHSX 631.

ASTR 796. Radiation and the Interstellar Medium. 3 Credits.
This course will investigate the theory of radiative processes relevant to astrophysical situations, including those acting on atoms, ions, and molecules and especially those relevant to material exterior to stars. Topics include: the physics of the interstellar medium in and between galaxies, including fluid dynamics; the quantum mechanics of atomic and molecular spectra and equilibrium and non-equilibrium thermodynamic processes; and observational diagnostics of interstellar gas, including microwave spectroscopy and radiative transfer modeling. (Same as PHSX 796.) Prerequisite: ASTR 692 or permission of instructor.

ASTR 797. Galaxies. 3 Credits.
This course will cover the observational and theoretical factors important in understanding galaxies. Topics covered may include galaxy stellar populations, galactic structure, kinematics and dynamics, interstellar and circumgalactic media, large scale structure and environment, galaxy demographics, and galaxy formation and evolution. (Same as PHSX 797.) Prerequisite: ASTR 692 or permission of instructor.

ASTR 798. High Energy Astrophysics. 3 Credits.
This course covers the physics of compact objects, including the equation of state of dense matter and stellar stability theory. Specific topics may include: The maximum mass of neutron stars, white dwarfs, and supermassive objects; black holes and accretion disks; compact X-ray sources and transient phenomena, including X-ray and gamma-ray bursts

and pulsars; particle acceleration models, neutrino production and energy loss mechanisms, supernovae, and neutron star production. (Same as PHSX 798.) Prerequisite: ASTR 692 or permission of instructor.

ASTR 815. Computational Methods in Physical Sciences. 3 Credits.

Advanced computer applications in physical science. General discussion and illustration of problem organization and solution by numerical and other methods with examples from physics, astronomy, and other physical sciences. Students will design, write, validate, and document computer programs to solve physical problems. (Same as PHSX 815 and CHEM 914.) Prerequisite: Six hours of computer science courses numbered 300 or above, and six hours of physics and/or astronomy courses numbered 300 or above.

Courses

PHSX 114. College Physics I. 1-4 Credits. LFE GE11 GE3N SWT NPS
Principles and applications of mechanics, fluids, heat, thermodynamics, and sound waves. Three class hours and one laboratory per week. This course emphasizes the development of quantitative concepts and problem solving skills for students needing a broad background in physics as part of their preparation in other major programs, and for those who wish to meet the laboratory science requirement of the College. Students who enroll in this course are expected to have had 3.5 years of college-prep math, including trigonometry. In special circumstances, permission to enroll in less than four hours may be obtained from the department. Please note that enrollment in fewer than 3 credit hours will not fulfill any general education or CLAS degree-level requirements. Not open to students with credit in PHSX 211 or PHSX 216 or PHSX 212 or PHSX 236. Prerequisite: Must be eligible for MATH 115.

PHSX 115. College Physics II. 1-4 Credits. LFE SWT NPS
A continuation of PHSX 114. Principles and applications of electricity, magnetism, light, atomic physics, and nuclear physics. Three class hours and one laboratory per week. In special circumstances, permission to enroll in less than four hours may be obtained from the department. Please note that enrollment in fewer than 3 credit hours will not fulfill any general education or CLAS degree-level requirements. Not open to students with credit in PHSX 212 or PHSX 236. Prerequisite: PHSX 114.

PHSX 150. Seminar in Physics, Astronomy and Engineering Physics. 0.5 Credits.
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PHSX 196. Contemporary Astronomy Laboratory. 1 Credits. LFE NLAB
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PHSX 201. Calculus Supplement to College Physics I. 1 Credits.
A calculus-based course in classical mechanics and thermodynamics for students who have had an algebra-based course in classical mechanics and thermodynamics. This course, combined with PHSX 114, covers the content of PHSX 211. Prerequisite: PHSX 114 and MATH 116 or MATH 125. Corequisite: MATH 126; and permission of the department.

PHSX 202. Calculus Supplement to College Physics II. 1 Credits.
A calculus-based course in electricity and magnetism for students who have had an algebra-based course in electricity and magnetism. This course, combined with PHSX 115, covers the content of PHSX 212. Prerequisite: PHSX 115 and permission of the department. Corequisite: MATH 126.

PHSX 209. Functions and Modeling. 3 Credits.
Study of the use of functions in mathematical modeling, with topics drawn from algebra, analytic geometry, statistics, trigonometry, and calculus. These topics include function properties and patterns, complex numbers, parametric and polar equations, vectors and various growth models. The course also includes inquiry methods, collaborative problem solving, the use of multiple representations and data analysis techniques, and the justification and presentation of results. Central to the course are investigative labs employing various technologies and software. The course is designed to help prepare students for secondary school mathematics teaching. (Same as MATH 209.) Prerequisite: MATH 126 or MATH 146.

PHSX 211. General Physics I. 1-4 Credits. LFE GE11 GE3N SWT NLEC
Introduction to classical mechanics and thermodynamics. Designed for students in engineering and physical science majors. Students with credit for PHSX 114 may receive permission from the department to enroll in fewer than four hours. Please note that enrollment in fewer than 3 credit hours will not fulfill any general education or CLAS degree-level requirements. Prerequisite: MATH 125 or MATH 145. Corequisite MATH 126 or MATH 146.

PHSX 212. General Physics II. 1-3 Credits. LFE GE3N SWT NLEC
Study of electricity, magnetism, waves, and optics. Designed for students in engineering and physical science majors. Students with credit for PHSX 115 may receive permission from the department to enroll in fewer than three hours. Please note that enrollment in fewer than 3 credit hours will not fulfill any general education or CLAS degree-level requirements. Prerequisite: PHSX 211 or EPHX 210 or PHSX 213; MATH 126 or MATH 146. Co-enrollment in MATH 127 or MATH 147 is strongly encouraged.

PHSX 213. General Physics I Honors. 1-5 Credits. LFE GE11 GE3N NPS
An honors section of PHSX 211 and PHSX 216. Credit for fewer than five hours requires permission of the department. Recommended for students with a strong math background who are either in the University Honors Program or intending to major in Astronomy, Physics, or Engineering

Physics. Courses in high school physics and chemistry are strongly recommended. Prerequisite: MATH 125 or MATH 145; co-requisite MATH 126 or MATH 146; and permission of instructor.

PHSX 214. General Physics II Honors. 1-4 Credits. LFE GE3N NPS

An honors section of PHSX 212 and PHSX 236. Credit for fewer than four hours requires permission of the department. Recommended for students with a strong math background who are either in the University Honors Program or intending to major in Astronomy, Physics, or Engineering Physics. Prerequisite: PHSX 216 together with PHSX 211; or PHSX 213, and permission of instructor. Corequisite: MATH 127 or MATH 147.

PHSX 216. General Physics I Laboratory. 1 Credits. LFE SWT NLAB
Experiments in classical mechanics and thermodynamics. The course includes practice in the ethics of recording and presentation of data. Counts as a laboratory science when accompanied by PHSX 211. Prerequisite: Corequisite: PHSX 211.

PHSX 236. General Physics II Laboratory. 1 Credits. LFE SWT NLAB
Experiments in electricity and magnetism, waves and sound. Students will practice data reduction and error analysis in ways that are consistent with professional ethics. Prerequisite: Corequisite: PHSX 212.

PHSX 313. General Physics III. 3 Credits. LFE GE3N
This course is an introduction to modern physics. The topics covered in this course include special relativity, optics, and introductions to quantum mechanics and its applications. Prerequisite: PHSX 212 and PHSX 236, or PHSX 214, or EECS 220, or EECS 221. Corequisite: MATH 320 or MATH 220 or MATH 221.

PHSX 315. Introduction to Computation for Physics and Astronomy. 3 Credits.
This course introduces the use of computational techniques as applied to solving problems in physics and astronomy. It serves as a gateway to the use of such methods in upper level classes and research. Highlighted techniques will include the use of numerical methods for the solution of differential equations encountered in physics and astronomy, the use of random numbers for simulation and modeling, data analysis using computers, and data visualization. Problems will be drawn from a wide variety of physical applications including mechanics, electromagnetism, thermodynamics, and stellar dynamics. Students will develop their own computer programs to investigate, illustrate, and report their results. Prerequisite: EECS 138 or EECS 168 or EECS 169, or permission of the instructor. Corequisite: PHSX 212 or PHSX 214.

PHSX 316. Intermediate Physics Laboratory I. 1 Credits. LFE
Experiments in optics and modern physics. Development of experimental skills, data reduction, error analysis, and technical writing. One lab meeting per week and one lecture per week on topics including error analysis and experimental design, and the development of professional ethics in regard to citation and data presentation. Prerequisite: Corequisite: PHSX 313.

PHSX 395. Physics Education Theory and Practice. 3 Credits.
This course focuses on how people teach, learn, and understand key concepts in physics, including an introduction to physics education research. Topics include student conceptions, assessments, impacts of student identity, metacognition, and nature of science. Current issues and tensions in science and math education will be discussed, especially as it relates to physics instruction. This course also provides students firsthand experience in planning and implementing a phenomena-based curriculum through teaching lessons in elementary or middle school classrooms. Prerequisite: Corequisite: PHSX 313.

PHSX 400. Topics in Physics and Astronomy: _____. 1-3 Credits.
A course on special topics in physics and astronomy, given as the need arises. Course may be repeated for different topics. Each section may have prerequisites to be determined by the instructor.

PHSX 420. Science and Policy. 3 Credits. AE52
An introduction to the relationship between science and public policy. The mutual interactions between public policy and scientific practice are explored within an ethical framework with examples that include energy and sustainability issues. An experiential course where students will be asked to develop and implement ethical solutions and engage meaningfully on a practicum project for local, regional, national, or international partners who are working on policy decisions which have technology implications. Honors credit is available for this course. Prerequisite: Eligibility for MATH 101.

PHSX 500. Special Problems. 1-5 Credits. AE61 CAP
Work in some area of physics beyond the topics or material covered in other courses. For some problems, continued enrollment in consecutive semesters may be appropriate. Prerequisite: One junior-senior course in science in an area related to the problem and consent of instructor.

PHSX 501. Honors Research. 1-4 Credits. AE61 CAP
This course is for students seeking Departmental Honors in Astronomy, Engineering Physics, or Physics to fulfill the undergraduate research requirement. At the completion of the required four hours of total enrollment, a written and oral report of the research is required. (Same as ASTR 501 and EPHX 501.) Prerequisite: Junior/Senior standing in Astronomy, Engineering Physics, or Physics, or permission of instructor.

PHSX 503. Undergraduate Research. 1-4 Credits. AE61 CAP
This course is for students seeking to fulfill the undergraduate research requirement. Students are expected to participate in some area of ongoing research in the department, chosen with the help of their advisor. At the end of the term, students will present their results in a seminar to other students and faculty. (Same as ASTR 503 and EPHX 503.) Prerequisite: Junior/Senior standing in Astronomy, Engineering Physics, or Physics, or permission of instructor.

PHSX 518. Mathematical Physics. 3 Credits.
Applications of modern mathematical methods to problems in mechanics and modern physics. Techniques include application of partial differential equations and complex variables to classical field problems in continuous mechanics, unstable and chaotic systems, electrodynamics, hydrodynamics, and heat flow. Applications of elementary transformation theory and group theory, probability and statistics, and nonlinear analysis to selected problems in modern physics as well as to graphical representation of experimental data. (Same as EPHX 518.) Prerequisite: PHSX 313; MATH 220 or MATH 221 or MATH 320; or permission of instructor.

PHSX 521. Mechanics I. 3 Credits.
Newton's laws of motion. Motion of a particle in one, two, and three dimensions. Motion of a system of particles. Moving coordinate systems. (Same as EPHX 521.) Prerequisite: PHSX 213 or PHSX 211 and PHSX 216; MATH 127 or MATH 147; MATH 290 or MATH 291; and MATH 220, MATH 221 or MATH 320.

PHSX 531. Electricity and Magnetism. 3 Credits.
This course will explore the properties of electric and magnetic fields, including electrostatics, Gauss' Law, boundary value methods, electric fields in matter, electromagnetic induction, magnetic fields in matter, the properties of electric and magnetic dipoles, and of dielectric and magnetic materials. (Same as EPHX 531.) Prerequisite: PHSX 214, or PHSX 212 and PHSX 236; PHSX 521 or EPHX 521 or special permission;

MATH 127 or MATH 147; MATH 290 or MATH 291; and MATH 220, MATH 221, or MATH 320.

PHSX 536. Electronic Circuit Measurement and Design. 4 Credits. LFE
A laboratory course that explores the theory and experimental techniques of analog and digital electronic circuit design and measurement. Topics include transient response, transmission lines, transistors, operational amplifiers, and digital logic. (Same as EPHX 536.) Prerequisite: PHSX 214 or PHSX 212 and PHSX 236; MATH 127 or MATH 147; and MATH 290 or MATH 291. PHSX 313 and 316 recommended.

PHSX 594. Cosmology and Culture. 3 Credits. AE42
A survey of modern physical cosmology, its recent historical roots, and creation myths from many world cultures. An examination of the effects of these stories on their parent cultures.

PHSX 598. Research Methods. 3 Credits. LFE
An introduction for pre-service teachers to the tools used by scientists to solve scientific problems. Topics include design of experiments and interpretation of their results, use of statistics, mathematical modeling, laboratory safety, ethical treatment of human subjects, writing scientific papers, giving oral presentations, and obtaining data from the scientific literature. Open only to students in the UKanTeach program. (Same as CHEM 598.) Prerequisite: At least one course at the 100 level or above in CHEM, MATH, or PHSX.

PHSX 600. Special Topics in Physics and Astrophysics: _____. 1-3 Credits.
Different topics will be covered as needed. This course will address topics in physics and astrophysics not covered in regularly offered courses. May be repeated if topic differs. (Same as EPHX 600.) Prerequisite: Permission of instructor.

PHSX 601. Design of Physical and Electronic Systems. 4 Credits. LFE AE61 CAP
A laboratory course emphasizing the application of physical principles to the design of systems for research, monitoring, or control. Topics include the use of microcomputers as controllers, interfacing microcomputers with measurement devices, and use of approximations and/or computer simulation to optimize design parameters, linear control systems, and noise. (Same as EPHX 601.) Prerequisite: Twelve hours of junior-senior credit in physics or engineering, including one laboratory course.

PHSX 611. Introductory Quantum Mechanics. 3 Credits.
An introduction to quantum mechanics, emphasizing a physical overview. Topics include the formalism of nonrelativistic quantum mechanics with emphasis on linear algebra, the 3-dimensional Schrodinger equation with applications to the hydrogen atom; harmonic oscillator; and time-independent perturbation theory. (Same as EPHX 511.) Prerequisite: PHSX 313, PHSX 521 or EPHX 521, and MATH 290 or MATH 291.

PHSX 615. Numerical and Computational Methods in Physics. 3 Credits.
An introduction to the use of numerical methods in the solution of problems in physics for which simplifications allowing closed-form solutions are not applicable. Examples are drawn from mechanics, electricity, magnetism, thermodynamics, and optics. (Same as EPHX 615.) Prerequisite: PHSX 313, MATH 320 or equivalent, and EECS 138 or equivalent.

PHSX 616. Physical Measurements. 4 Credits. LFE
A laboratory course emphasizing experimental techniques and data analysis, as well as scientific writing and presentation skills. Experiments will explore a range of classical and modern physics topics. Students will also practice ethical decision making using case studies appropriate for the discipline. (Same as EPHX 616.) Prerequisite: PHSX 313, PHSX 316 or EPHX 316, and PHSX 521 or EPHX 521. (PHSX 521 or EPHX 521 may be taken concurrently.)

PHSX 621. Mechanics II. 3 Credits.
Continuation of PHSX 521. Lagrange's equations and generalized coordinates. Mechanics of continuous media. Tensor algebra and rotation of a rigid body. Special relativity and relativistic dynamics. (Same as EPHX 621.) Prerequisite: EPHX 521 or PHSX 521.

PHSX 631. Electromagnetic Theory. 3 Credits.
Maxwell's equations, wave propagation, optics and waveguides, radiation, relativistic transformations of fields and sources, use of covariance and invariance in relativity. Normally a continuation of PHSX 531. (Same as EPHX 631.) Prerequisite: EPHX 531 or PHSX 531.

PHSX 641. Introduction to Nuclear Physics. 3 Credits.
Experimental methods in nuclear physics, elementary concepts and simple considerations about nuclear forces, alpha and beta decay, gamma radiation, nuclear structure, and reaction systematics. (Same as EPHX 641.) Prerequisite: PHSX 313 and PHSX 611 or EPHX 611.

PHSX 655. Optics. 3 Credits.
Geometric optics. Wave properties of light: interference, diffraction, coherence. Propagation of light through matter. Selected topics in modern optics, e.g., lasers, fibers. (Same as EPHX 655.) Prerequisite: PHSX 531 or EPHX 531 or PHSX 212 or PHSX 214 and special permission from instructor.

PHSX 661. Introduction to Elementary Particle Physics. 3 Credits.

This course covers properties and interactions of quarks, leptons, and other elementary particles; symmetry principles and conservation laws; broken symmetry; gauge bosons; the fundamental interactions, grand unified theories of strong, electromagnetic, and weak interactions; the cosmological implications of elementary particle physics. (Same as EPHX 661.) Prerequisite: PHSX 611 or EPHX 611, and MATH 220, MATH 221, or MATH 320.

PHSX 671. Thermal Physics. 3 Credits.
This course introduces thermodynamics from statistical considerations and presents the associated techniques for calculating the thermodynamic properties of systems. Highlighted applications of these techniques include the elementary kinetic theory of transport processes and statistical descriptions of both Fermi-Dirac and Bose-Einstein systems. (Same as EPHX 671.) Prerequisite: PHSX 611 or EPHX 611.

PHSX 681. Introduction to Solid State Physics. 3 Credits.
This course is an introduction to the properties of crystals and amorphous solids, including lattice vibrations and thermal properties, with a particular emphasis on the behavior of electrons and holes in the energy bands of metals, semiconductors, superconductors, and insulators. (Same as EPHX 681.) Prerequisite: PHSX 313 and PHSX 611 or EPHX 611.

PHSX 691. Astrophysics I. 3 Credits.
An introduction to radiation processes, thermal processes, and radiative transfer in stellar atmospheres and the interstellar medium. (Same as ASTR 691 and EPHX 691.) Prerequisite: PHSX 313 and ASTR 391.

PHSX 693. Gravitation and Cosmology. 3 Credits.
An overview of topics relevant to gravitation and modern cosmology: special relativity, tensor notation, the equivalence principle, the Schwarzschild solution, black holes, and Friedmann models. Cosmic black body radiation, dark matter, and the formation of large-scale structure. The idea of quantum gravity and an introduction to the current literature in cosmology. (Same as EPHX 693.) Prerequisite: PHSX 313, PHSX 521 (or EPHX 521), and MATH 220, MATH 221, or MATH 320.

PHSX 700. Colloquium. 1 Credits.

Topics of current interest in physics, astronomy, and atmospheric science. Repeated enrollments are permitted.

PHSX 702. Introductory Physics Pedagogy. 1 Credits.
This course will address basic elements of pedagogy in specific relation to the teaching of physics and astronomy labs. It contains such elements as: peer and instructor evaluations of teaching, reading and discussion of pedagogical materials, development of online course material, and discussion of teaching methods. This course may be repeated for credit. Prerequisite: Permission of instructor.

PHSX 703. Proposal Writing. 1 Credits.
Means and methods for preparing a successful proposal. This course will discuss how to find funding and other award opportunities. Students will learn how to develop an effective application and will complete an application. Intended for early career graduate students and advanced undergraduate students.

PHSX 711. Quantum Mechanics I. 3 Credits.
Linear vector spaces. Bra-ket notation for abstract vector spaces and its applications in quantum mechanics. Angular momentum and Clebsch Gordan coefficients. Product spaces; Heisenberg picture. Spin. Fermi-Dirac and Bose-Einstein statistics. Time independent perturbation theory of first and second order. Prerequisite: PHSX 611 or EPHX 611, MATH 220 or MATH 221 or MATH 320.

PHSX 717. Graduate Seminar. 1 Credits.
First year graduate students meet to survey research opportunities in the department and develop skills in giving oral presentations in physics and related areas. Students will also learn about topics in responsible scholarship that may include: the origin of ideas and the allocation of credit, the treatment of data, scientific misconduct, intellectual property and entrepreneurship, the researcher in society, collaborative research, mentor/trainee responsibilities, and safe practices.

PHSX 718. Mathematical Methods in Physical Sciences. 3 Credits.

Review of complex variable theory; introduction to the partial differential equations of physical systems; Fourier analysis; special functions of mathematical physics; and chemistry. (Same as CHEM 718.) Prerequisite: Two semesters of junior-senior mathematics.

PHSX 719. Physics and Astronomy Graduate Problem Solving. 1 Credits.
This course teaches students skills in solving graduate level physics and astronomy problems. Graded on a satisfactory/unsatisfactory basis.

PHSX 721. Chaotic Dynamics. 3 Credits.
Topics covered may include the following: dynamical systems, attractors, sensitive dependence on initial conditions, chaos, one-dimensional maps, strange attractors and fractal dimensions, fat fractals, the horseshoe map, symbolic dynamics, linear stability of periodic orbits, stable and unstable manifolds, Lyapunov exponents, topological entropy, quasiperiodicity, strange nonchaotic attractors, nonattracting chaotic sets, fractal basin boundaries, renormalization group analysis, intermittency, crisis and chaotic transients. Prerequisite: Mechanics (PHSX 521, or its equivalent), ordinary differential equations (MATH 320, or its equivalent), and some computer programming knowledge.

PHSX 727. Advanced Geophysics: _____. 1-3 Credits.
Topics to vary with demand and include heat flow, wave propagation, synthetic seismograms, groundwater exploration, geothermal exploration, electrical methods in exploration, rock mechanics-tectonophysics, rock magnetism, geomagnetism, paleomagnetism, geophysical inverse theory, and others upon sufficient demand. May be repeated for different topics. (Same as GEOL 771.) Prerequisite: GEOL 572 or consent of instructor.

PHSX 741. Nuclear Physics I. 3 Credits.
Experimental methods in nuclear physics, elementary concepts and simple considerations about nuclear forces, alpha and beta decay, gamma radiation, nuclear structure, and reaction systematics. Prerequisite: PHSX 511.

PHSX 761. Elementary Particles I. 3 Credits.
Particle accelerators and detectors; quarks and leptons; invariance principles and conservation laws; strong, electromagnetic, and weak interactions of elementary particles; unification of electroweak and other interactions. Prerequisite: Corequisite: PHSX 711.

PHSX 781. Solid State Physics I. 3 Credits.
Classification of solids, structure and symmetry of crystals; lattice vibrations and thermal properties of solids; electric and magnetic properties; electron theory of metals and semiconductors; electronic and atomic transport processes; theory of ionic crystals. Prerequisite: PHSX 511 (or CHEM 648) and PHSX 671 (or CHEM 646).

PHSX 791. Seminar in Astrophysics, Cosmology, and Space Physics. 1 Credits.
Seminar designed to cover current topics in the physics of the Universe beyond the solar system. Content will vary. Graduate students engaged in or preparing for research may repeat enrollments in this course. Open to undergraduates with twelve hours of physics/astronomy courses numbered 500 or above, or consent of instructor.

PHSX 792. Topics in Advanced Astrophysics. 3 Credits.
This course will address one or more of the following advanced topics in astrophysics: high energy astrophysics, nuclear astrophysics, galactic and extragalactic astrophysics, space physics, cosmology, astro-bioyphysics, and the interstellar and intergalactic media (ISM/IGM.) This course may be repeated for credit if topical content differs. (Same as ASTR 792.) Prerequisite: ASTR 692 or permission of instructor.

PHSX 793. Physical Cosmology. 3 Credits.
Discussion of how fundamental laws of physics govern the evolution of the universe as a whole along with its structure. Survey of cosmogenic clues in the observable universe, including observed structures, cosmic background radiation and evidence for dark matter. Development of the universe, including theories of initial conditions; cosmological phase transitions; generation of possible relics and dark matter; symmetry breaking; baryon asymmetry; nucleosynthesis; recombination, gravitational instability and the formation of structure; current experimental techniques. Prerequisite: PHSX 718. Recommended: PHSX 693.

PHSX 794. Interiors and Atmospheres. 3 Credits.
This course covers energy generation, flow, hydrostatic equilibrium, equation of state in stars and exoplanets, including the dependence of stellar parameters (central surface temperature, radius, luminosity, etc.) on stellar mass and its relation to physical constants. Other topics may include the relationship of these parameters to stellar evolution; stellar and exoplanet interiors, opacity sources, radiative and convective energy flow; nuclear reactions in stars; and the atmospheric structure of exoplanets. (Same as ASTR 794.) Prerequisite: ASTR 692 or permission of instructor.

PHSX 795. Space Plasma Physics. 3 Credits.
The physics of fully ionized gases in magnetic fields and their application to interplanetary processes, planetary radiation belts, and the sun. The motion of charged particles in magnetic fields, magnetohydrodynamic waves, the solar wind, the ionosphere, and the magnetosphere. (Same as ASTR 795.) Prerequisite: PHSX 621. Corequisite: PHSX 631.

PHSX 796. Radiation and the Interstellar Medium. 3 Credits.
This course will investigate the theory of radiative processes relevant to astrophysical situations, including those acting on atoms, ions, and

molecules and especially those relevant to material exterior to stars. Topics include: the physics of the interstellar medium in and between galaxies, including fluid dynamics; the quantum mechanics of atomic and molecular spectra and equilibrium and non-equilibrium thermodynamic processes; and observational diagnostics of interstellar gas, including microwave spectroscopy and radiative transfer modeling. (Same as ASTR 796.) Prerequisite: ASTR 692 or permission of instructor.

PHSX 797. Galaxies. 3 Credits.
This course will cover the observational and theoretical factors important in understanding galaxies. Topics covered may include galaxy stellar populations, galactic structure, kinematics and dynamics, interstellar and circumgalactic media, large scale structure and environment, galaxy demographics, and galaxy formation and evolution. (Same as ASTR 797.) Prerequisite: ASTR 692 or permission of instructor.

PHSX 798. High Energy Astrophysics. 3 Credits.
This course covers the physics of compact objects, including the equation of state of dense matter and stellar stability theory. Specific topics may include: The maximum mass of neutron stars, white dwarfs, and supermassive objects; black holes and accretion disks; compact X-ray sources and transient phenomena, including X-ray and gamma-ray bursts and pulsars; particle acceleration models, neutrino production and energy loss mechanisms, supernovae, and neutron star production. (Same as ASTR 798.) Prerequisite: ASTR 692 or permission of instructor.

PHSX 800. Graduate Problems. 1-5 Credits.
Advanced laboratory problems, special research problems, or library reading problems. Repeated enrollments are permitted.

PHSX 801. Advanced Topics. 1-3 Credits.
Lectures on advanced material not covered by regular courses. The topics are not limited but generally address recent experimental or theoretical developments in subjects such as superconductivity, nuclear physics, elementary particle physics, quantum field theory, gauge and unified theories, nonlinear or chaotic systems, space plasma physics, and astrophysics and cosmology. Repeated enrollments are permitted.

PHSX 811. Quantum Mechanics II. 3 Credits.
This advanced course in quantum mechanics covers scattering theory, time dependent perturbation theory, density-matrix formalism, entanglement, and relativistic quantum mechanics, e.g. Klein-Gordon and Dirac equations. Additional advanced topics may be covered at the discretion of the instructor. Prerequisite: PHSX 711.

PHSX 815. Computational Methods in Physical Sciences. 3 Credits.

Advanced computer applications in physical science. General discussion and illustration of problem organization and solution by numerical and other methods with examples from physics, astronomy, and other physical sciences. Students will design, write, validate, and document computer programs to solve physical problems. (Same as ASTR 815 and CHEM 914.) Prerequisite: Six hours of computer science courses numbered 300 or above, and six hours of physics and/or astronomy courses numbered 300 or above.

PHSX 821. Classical Mechanics. 3 Credits.
Vector and tensor notation; review of Newtonian mechanics; Lagrangian mechanics; linear vector spaces and matrix theory with applications to the theory of small oscillations; rigid bodies; Hamiltonian formalism. Special relativity. Prerequisite: Twelve hours of junior-senior courses in physics.

PHSX 831. Electrodynamics I. 3 Credits.
Electrostatics and magnetostatics; Maxwell's equations; plane waves; waveguides. Prerequisite: PHSX 718 and PHSX 821.

PHSX 841. Nuclear Physics II. 3 Credits.
Nuclear forces and the two-body problem; nuclear models; phenomenological treatment of nuclear reactions and decay processes. Prerequisite: PHSX 741 and PHSX 811.

PHSX 855. Advanced Optics. 3 Credits.
Advanced topics in optics that may include: Laser principles and techniques, light propagation in dielectrics, absorption and luminescence, interaction of light with free electrons and phonons, nonlinear optics, photonic devices, and optical spectroscopy.

PHSX 861. Elementary Particles II. 3 Credits.
Theoretical analysis of the standard model of strong and electroweak interactions. Applications to decay and scattering processes with comparison to experiments. Selected topics in non-perturbative physics. Examples of tests to probe beyond the standard model. Prerequisite: PHSX 761. Corequisite: PHSX 911.

PHSX 871. Statistical Physics I. 3 Credits.
Review of and advanced topics in thermodynamics; the Maxwell relations; the third law; phase transitions. Kinetic theory: the Boltzmann equation; transport phenomena. Statistical mechanics: ideal Maxwell-Boltzmann, Fermi-Dirac and Bose-Einstein gases; ensemble theory; derivation of the laws of thermodynamics. Prerequisite: PHSX 711 and PHSX 821. PHSX 671 is recommended.

PHSX 881. Solid State Physics II. 3 Credits.
More advanced topics in solid state physics that may include: diamagnetism, paramagnetism, ferromagnetism, and antiferromagnetism; electron and nuclear spin magnetic resonance; dielectric properties and ferroelectricity; photoconductivity and luminescence. Prerequisite: PHSX 631 and PHSX 711 (or CHEM 750).

PHSX 885. Materials Modeling. 3 Credits.
This course provides an overview of various computational methods used to describe and model materials. Topics may include, but are not limited to, classical potentials, molecular dynamics, tight-binding, k.p theory, density functional theory, and machine learning. Prerequisite: PHSX 781 and PHSX 815 or consent of instructor.

PHSX 886. Materials Characterization. 3 Credits.
This course provides an overview of various experimental material characterization methods. Topics may include, but are not limited to, diffraction, electron microscopy methods, crystallography, scanning probe microscopy, optical and electron spectroscopy techniques, large-scale synchrotron-based characterization techniques, transport, and magnetic properties measurements. Prerequisite: PHSX 781 or consent of instructor.

PHSX 895. Plasma Physics. 3 Credits.
Magnetohydrodynamics, including discussion of shocks, waves, and stability theory; statistical mechanical foundations; kinetic theory; microstability; non-linear phenomena. Prerequisite: PHSX 795.

PHSX 899. Master's Research/Thesis. 1-10 Credits.
Research work (either experimental or theoretical) in physics for students working toward the master's degree. Repeated enrollments are permitted. Graded on a satisfactory progress/limited progress/no progress basis.

PHSX 911. Quantum Mechanics III. 3 Credits.
Path integral formulation of quantum mechanics. Introduction to quantum field theory using the canonical approach and using the path integral approach. Application of perturbation theory in quantum electrodynamics. Selected applications in condensed matter, nuclear, and particle physics. Prerequisite: PHSX 811.

PHSX 912. Quantum Field Theory. 3 Credits.

Survey of problems in quantum field theory. Functional methods. Renormalization and renormalization group. Role of symmetries. Gauge field theories. Symmetry breaking. Prerequisite: PHSX 911.

PHSX 915. Relativity. 3 Credits.
Reviews of special relativity, manifolds, tensors, and geometry. General coordinate covariance and general relativity. Applications to classical theory of gravitation: weak field tests, isotropic, homogeneous cosmology, Schwarzschild solution. Selected advanced topics. Prerequisite: A total of 10 hours of junior/senior work in physics and mathematics, including at least concurrent enrollment in MATH 646.

PHSX 917. Seminar in Theoretical Physics. 1 Credits.
Graduate students engaged in or preparing for research may repeat enrollments in this course. The content will vary.

PHSX 931. Electrodynamics II. 3 Credits.
Inhomogeneous Maxwell's equations and multipole radiation fields; special theory of relativity; radiation from accelerated charges; scattering and dispersion. Prerequisite: PHSX 831.

PHSX 947. Seminar in Nuclear Physics. 1 Credits.
Graduate students engaged in or preparing for research may repeat enrollments in this course. The content will vary.

PHSX 957. Seminar in Physics Education Research. 1 Credits.
Seminar designed to cover current topics in physics education research. Content will vary. Graduate students engaged in or preparing for research may repeat enrollments in this course.

PHSX 967. Seminar in Particle Physics. 1 Credits.
Graduate students engaged in or preparing for research may repeat enrollments in this course. The content will vary.

PHSX 971. Advanced Statistical Mechanics. 3 Credits.
Advanced equilibrium statistical mechanics and introduction to nonequilibrium statistical mechanics. Topics include: the theory of liquids, critical phenomena, linear response theory and time correlation functions, Langevin dynamics, and molecular hydrodynamics. (Same as CHEM 950.) Prerequisite: PHSX 871 or CHEM 917.

PHSX 987. Seminar in Solid State Physics. 1 Credits.
Graduate students engaged in or preparing for research may repeat enrollments in this course. The content will vary.

PHSX 999. Ph.D. Dissertation Research. 1-12 Credits.
Research work (either experimental or theoretical) in physics for students working toward the Ph.D. degree. Repeated enrollments are permitted. Graded on a satisfactory progress/limited progress/no progress basis.