Department of
Physics
College of Science

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Degrees offered: Bachelor of Science (BS), Bachelor of Arts (BA), Master of Science (MS), and Doctor of Philosophy (PhD) in Physics; BS and BA in Physics Teaching; BS and BA in Composite Teaching—Physical Science (Physics)

Undergraduate emphases: *BS*—Professional Emphasis or Applied Emphasis; **Graduate specializations:** *MS*—Upper Atmospheric Physics; *PhD*—Electromagnetic and Plasma Theory, Space Science, Surface Physics, and Theoretical Physics

Undergraduate Programs

Objectives

The Physics Department embraces undergraduate students from all quarters of the University—in introductory courses required for majors by various departments, in courses for more general audiences that are part of the University Studies Program, and in upper-level courses designed primarily to fulfill bachelor's degree requirements in Physics. These courses, and the degree programs offered, are strongly impacted by the department's central goals:

1. to communicate the beauty and utility of the fundamental principles of the physical universe and the power of describing nature in quantitative terms,

2. to create new knowledge,

3. to foster critical and creative thinking,

4. to enhance the ability of citizens to participate in a technological democracy,

5. to assist in the preparation of elementary and secondary school teachers,

6. to provide opportunities for students to sharpen their communication and interpersonal skills, and

7. to develop new tools and texts to improve physics pedagogy.

The degree programs of the department are constructed to be rigorous, yet flexible, and are intended to help students prepare for careers in academia, government and industrial laboratories, medicine, law, teaching, and business. Required course and laboratory work in these programs carefully balances theory and experiment. Because the department believes that one must participate in discovery to understand science, undergraduates are encouraged to engage in departmental research early in their studies, and a formal research experience is integral to most departmental programs. The department's Get Away Special activities provide excellent opportunities for students of all backgrounds to participate in space related research.

Requirements

Departmental Admission and Graduation Requirements. New freshmen admitted to USU in good standing qualify for admission to the degree programs in Physics. Admission in good standing for students transferring from another institution requires

a minimum transfer GPA of 2.2, while students transferring from another USU major are required to have a minimum total GPA of 2.0. Students wishing to complete the Teaching Major in Physics must apply for admission to the Secondary Education program as well. Requirements for admission to the **Secondary Teacher Education Program (STEP)** include a minimum GPA of 2.75 in either Phyx 2110 and 2120, or Phyx 2210 and 2220; and at least 60 total credits completed with a minimum GPA of 2.75. A Composite Teaching Major in Physical Science is available through either the Physics or the Chemistry and Biochemistry departments. Students applying for admission to the STEP with the Composite major must satisfy the latter requirements, plus a minimum GPA of 2.75 in Chem 1210, 1220, 1230, and 1240.

Students may use no more than one course with the *P-D-F* option to satisfy a major or minor requirement in Physics. All other courses used to satisfy major or minor requirements must be completed with at least a *C-* grade, and the total GPA in all required Physics courses must be at least 2.3. The Teaching Major and Teaching Minor in Physics and the Composite Teaching Major in Physical Science require a 2.75 minimum GPA in Physics courses and a minimum 2.75 overall GPA for graduation.

College of Science Requirements. The College of Science requires a year of mathematics (8 credits) and a year sequence in science (6-8 credits) for all of its majors. For Physics majors, the College of Science requirements are Math 1210 and 1220; and one of the following pairs of courses: Biol 1210 and 1220, Chem 1210 and 1220, or Geol 1150 and 3200.

Bachelor's Degrees and Core Requirements. The Physics Department awards the following degrees: BS in Physics, BA in Physics, BS in Physics with a Professional Emphasis, BS in Physics with an Applied Emphasis, BS in Mathematics and Physics Dual Major Option, BS in Physics Teaching, and BS in Composite Teaching—Physical Science.

Except for the two Teaching Majors, all degrees require a **common core**: College of Science requirements; Math 2210; Phyx 2210 and 2220 (preferred) or Phyx 2110 and 2120; Phyx 2500, 2710, 3550, 3600, 3870, and 4900. The specific requirements beyond this core for the various bachelor degrees are:

1. Bachelor of Science in Physics: Math 2250; Phyx 3650 or 3700; 8 credits in Physics at the 3500 level and above (excluding USU Depth courses).

2. Bachelor of Arts in Physics: University language requirements; Math 2250; 6 credits in Physics at the 3500 level and above (excluding USU Depth courses); Phil 4310, 4320.

3. Bachelor of Science in Physics with a Professional Emphasis: Math 2250; Phyx 3650, 3700, 3750, 3880, 4550, 4600, 4700, 4710, 4900.

4. Bachelor of Science in Physics with an Applied Emphasis: Math 2250; Phyx 3650, 3700, 3880; 12 credits in other technical departments at the 3000 level or above (excluding USU Depth courses). The latter courses must have a coherent theme and must be approved by the Physics advisor.

5. Mathematics and Physics Dual Major Option: Math 2270, 2280, 4200, 4310, 5210, 5710; 6 credits in Mathematics above the 4600 level, excluding Math 5570 and 5580 (Actuarial Math I and II); Phyx 3650 or 3700; 8 credits in Physics at the 3500 level and above (excluding USU Depth courses).

Minor in Physics. Majors in other departments may obtain a minor in Physics by successfully completing Phyx 2110 and 2120, or Phyx 2210 and 2220; plus 10 additional credits selected from Phyx courses at the 2500 level and above (not to include Phyx courses designated as USU Depth courses). Note that Math 1100 or 1210 is a prerequisite for Phyx 2110, Math 1210 is a prerequisite for Phyx 2210, and Math 1220 is a prerequisite for Phyx 2710.

Bachelor of Science in Physics Teaching. Courses required for the Bachelor of Science in Physics Teaching are: College of Science requirements; Math 1210, 1220, 2250; Stat 3000; Phyx 2210 and 2220 (preferred) or Phyx 2110 and 2120; Phyx 1000, 2500, 2710, 3550, 3870; 5 credits in Physics above the 3000 level (including USU Depth courses); Sci 4300; and 6 credits in science, with 3 in each of the two areas not covered by the College of Science science sequence requirement. Students seeking this degree must complete the requirements for the **Secondary Teacher Education Program (STEP).**

Teaching Minor in Physics. Students who complete the Secondary Teacher Education Program (STEP) are eligible to obtain a Teaching Minor in Physics by successfully completing Phyx 2110 and 2120, or Phyx 2210 and 2220; Phyx 1000; 6 additional credits in Physics chosen from Phyx 2500 and/or courses above the 3000 level (including USU Depth courses); Sci 4300 or, if Sci 4300 is required by the student's major, 2 credits in science (not including Physics) not required by the major. Note that Math 1100 or 1210 is a prerequisite for Phyx 2110, Math 1210 is a prerequisite for Phyx 2210, and Math 1220 is a prerequisite for Phyx 2710.

Bachelor of Science in Composite Teaching–Physical Science. Courses required for the Bachelor of Science in Composite Teaching—Physical Science are: Math 1210, 1220; Stat 3000; Phyx 2210 and 2220 (preferred), or Phyx 2110 and 2120; Phyx 1000, 1030 or 3030; 5 credits in Physics from Phyx courses at the 2500 level and above (including USU Depth courses); Chem 1210, 1220, 1230, 1240, 2300 or 2310, 2330; Biol 1010; Geol 1150; Bmet 2000; and Sci 4300. Students seeking this degree must complete the requirements for the **Secondary Teacher Education Program (STEP).**

Additional Information

Information concerning degree programs, recommended schedules of courses, career opportunities, and opportunities to participate in the Get Away Special activities and in other areas of undergraduate research may be obtained by consulting the Physics advisor in SER 250. Also see the department's website at: **http://www.physics.usu.edu/**.

Financial Support

The Physics Department has several small scholarship funds available for physics majors with excellent academic records. In addition, there are a number of Get Away Special (GAS) scholarships for students interested in designing and constructing experiments to be flown on the Space Shuttle and in participating in other GAS activities. Inquiries should be made with the Physics advisor in SER 250.

Graduate Programs

Admission Requirements

In addition to the general requirements for admission established by the School of Graduate Studies (see pages 72-73), the department admission committee bases its decisions for offering admission on the following criteria: review of applicants' undergraduate records, letters of recommendation, performance in graduate courses (if any), performance in research (if any), and scores on the General portion of the Graduate Record Examination. Students whose native language is not English are strongly encouraged to submit to the School of Graduate Studies results of the Test of Spoken English (TSE). Regardless, nonnative English speakers must submit a score for the Test of English as a Foreign Language (TOEFL). If a satisfactory score on the TSE is not provided, such students will be required to take a test given by the Intensive English Language Institute (IELI) at USU. The purpose of this test is to guide the selection of remedial language courses, if needed, to help with physics coursework comprehension. (See also *Financial Assistance,* page 389.)

Placement

Prior to registering for graduate courses for the first time, each student will consult with the Graduate Student Tracking Committee and the departmental advisor. Based on these discussions, the student will be advised to register for courses in either the Physics Department standard curriculum or advanced curriculum. Continuing advisement concerning courses will be provided by the Graduate Student Tracking Committee, the departmental advisor, and the student's graduate supervisory committee.

Qualification Requirements

Each student enrolled in the PhD program will be evaluated for qualification for PhD work. Consideration of qualification will occur no later than the end of the second semester after the student has been admitted for study in the PhD program and has taken a first graduate course in physics. Evaluation will be based on whatever relevant information the student wishes to have presented on his or her behalf (coursework, research, TA performance, subject GRE, etc.), but must include a faculty evaluation of coursework in physics for courses taken at USU. Normally, the student should present the results of at least four physics courses. Students admitted to the PhD program with considerable coursework from another institution, who have not taken at least four courses in physics at USU, must present a qualification seminar to the Department of Physics on research he or she has done during the preceding year at USU. Based on the various pieces of information presented on behalf of the student, the department will judge whether or not the student is qualified to continue in the PhD program. If not, a student already having an MS in physics from USU will be asked to leave. A student without an MS in physics from USU will be invited to finish his or her MS degree. Upon completion, the student can reapply to the PhD program, but acceptance will be contingent on the evaluation of the student's graduate work to that point.

Degree Programs

Master of Science. In addition to the above general requirements, students completing a Plan A MS degree must complete four of the ten required PhD courses listed below (see Doctor of Philosophy). Plan B MS students must complete five of the ten courses, and Plan C MS students must complete six of the ten courses. The student must also submit and orally defend either a thesis (Plan A) or a research report (Plan B) at the discretion of the student's supervisory committee. Plan A and Plan B MS candidates must present a colloquium to the department on the research topic during the time the thesis or research report is being written. The department also accepts Plan C, which has no research component. For Plan C, the student must complete 33 credits of graduate-level classwork, the composition of which shall include the required courses listed above. In addition, the student must present a seminar and a paper to his or her supervisory committee on a topic related to educational or managerial aspects of physics graduate education, which is chosen by his or her supervisory committee.

Master of Science (Upper Atmospheric Physics Specialization). The department offers a specialization in Upper Atmospheric Physics for MS students. This degree is a Plan A MS. In consultation with his or her advisor, the student selects a minimum of 18 credits of classwork from the following courses: Phyx 4600, 6240, 6310, 6320, 6330, 6340, 7210, 7500; 3 to 6 additional credits may be chosen from courses in electrical engineering, computer science, mathematics, and biometeorology. The student may gain from 6 to 12 credits by research, to be written up as a thesis that must be defended orally. In addition, the student must present a colloquium on the topic of his or her research.

Doctor of Philosophy. In addition to the general requirements, a total of 10 courses (30 credits) are required for all PhD students. The required courses are: Phyx 5340, 5350, 6010, 6110, 6210, and 6410; one State of Matter course; one Advanced Laboratory course; and two courses in Advanced Topics. The State of Matter requirement can be fulfilled by taking any one of Phyx 6330, 6530, or 6930. The Advanced Laboratory requirement can be fulfilled with either Phyx 5870 or 7210. This requirement may also be fulfilled with Phyx 7500, as long as Phyx 7500 consists of a hands-on experience with advanced instrumentation and with department head approval. These courses must be completed no more than one year after PhD qualification. The student must also take an oral candidacy examination, consisting of a presentation made by the student, then followed by questions from departmental faculty. The presentation and questions will be based upon a research topic set by the student's supervisory committee. The candidacy oral examination will normally occur no later than the fifth semester after the student begins graduate coursework. The student will have at least two months to prepare for the examination.

The student must also complete a research dissertation and give an oral defense of the dissertation. Furthermore, the PhD candidate is expected to give two colloquia to the department. The first of these will normally be given at the time of submission of the research proposal, with the other given at the time the dissertation is completed.

Research

Space Science. The Physics Department is active in the field of atmospheric and space science, in close association with the interdisciplinary Center for Atmospheric and Space Sciences and the Space Dynamics Laboratory. Atmospheric and space science involves many areas of physics, in addition to such disciplines as engineering, chemistry, and meteorology. At USU, these groups enjoy a strong cooperative relationship and, as a result, the atmo-

spheric and space science program has flourished for many years. Once the departmental requirements have been met, students may select courses from the offerings of the associated departments suited for their particular interests and needs while they gain research experience on challenging problems in atmospheric and space science. Opportunities are available for students in both experimental and theoretical projects. These include participation in instrument development and data analysis related to rocket, satellite, and space shuttle projects and projects in experimental design and data analysis related to incoherent-scatter and coherent radars, ground-based magnetometer, and ground-based optical instruments including a LIDAR system. Opportunities also exist in theoretical modeling of physical processes occurring in both the neutral atmosphere and in the plasma in the solar-terrestrial environment.

Electromagnetic and Plasma Theory. The study of perfect conductors in the presence of magnetic fields has interesting applications to space plasmas, and illuminates certain properties of quantum fluids such as superconductors. Using minimum energy principles, researchers attempt to model magnetic structures such as flux ropes near Venus, filaments in the solar corona, and fluxoids in super conductors.

Surface Physics. The surface physics group has an active experimental research program studying the structure, growth, dynamics, electronic properties, and optical properties of surfaces, interfaces, and adsorbed layers. The group has expertise in the interactions of electrons, ions, and photons with materials. Experimental techniques used within the group include atomic force microscopy (AFM), Auger electron spectroscopy (AES), infrared spectroscopy, ion scattering spectroscopy, ion implantation, low-energy electron diffraction (LEED), photoemission spectroscopy, scanning electron microscopy (SEM), scanning tunneling microscopy (STM), secondary ion mass spectroscopy (SIMS), thermal deflection spectroscopy, ultrafast femtosecond laser spectroscopy, vapor pressure adsorption isotherms, and x-ray diffraction. This interdisciplinary research brings together the fields of solid-state physics, surface physics and chemistry, optics, physical chemistry, and electrochemistry through active collaborations between Physics, Chemistry and Biochemistry, Mechanical and Aerospace Engineering, and other departments. It includes both basic and applied research.

Physics of Quantum Devices. The rapid advance of technology has made quantum physics an indispensable foundation of the nanoscale devices. The Physics Department is positioned to explore this new field with two complementary research themes. The first theme is to study the growth of novel electronic/photonic materials involving group III-VII elements. Bulk and surface analytic tools will be used to characterize the materials. This part of the research is currently under development. The second theme is to use the most advanced surface science techniques to fabricate nanoscale structures on semiconductor surfaces. The interdisciplinary nature of this field provides a stimulating research environment for faculty and students with backgrounds in physics, electrical engineering, material sciences, and chemistry.

Theoretical Physics. The department maintains an active research program in theoretical physics via its Field Theory Group. The principal focus of this group is on unified field theories, gravitational theory, classical and quantum field theory, and geometric methods in mathematical physics. Current research projects include: conformal and scale invariant gravity theories and unified field theories, Weyl-geometric quantization, exact solutions in Gauss-Bonnet extended gravity, classical and quantum dynamics of the gravitational field, symmetries and conservation laws in relativistic field theories, Lagrangian and Hamiltonian formulation of field theory, and application of geometrical methods in physics. Weekly seminars and ongoing collaborations with members of the USU Mathematics and Statistics Department and the University of Utah Physics Department provide an active research environment that allows for substantial interaction between students and faculty.

Physics Education. The USU Physics Department is engaged in the study of how to improve the teaching and learning of physics. The program currently emphasizes introductory and general education courses and involves development of hands-on, inquiry-based curricula for lecture and laboratory, development of associated laboratory and multimedia equipment and modules, preparation of new texts and workbooks, sponsorship of undergraduate research, and outreach to the pre-college community.

Complex Materials and Dynamics. Current work at USU in the interdisciplinary area of complex systems includes theoretical and experimental studies of the physical properties of granular materials, development of new data analysis techniques for uncovering evidence for determinism in erratic signals, and identification and implementation of perturbative methods for controlling complex behavior in electrical circuits, spatially extended systems (such as flames), and in wildlife populations.

Financial Assistance

Financial assistance in the form of teaching assistantships and fellowships is awarded by the department. Research assistantships are available from research groups or individuals. Some support for teaching laboratory sections or grading papers is available. To be eligible for a teaching assistantship (TA), a student must successfully complete a graduate TA workshop. Nonnative English-speaking students must pass a test of spoken English (or submit a satisfactory TSE score) administered by the Intensive English Language Institute before being admitted to the TA workshop. The MS specialization in Upper Atmospheric Physics is a Western Regional Graduate Program (see page 71).

Career Opportunities

Master's degree holders in physics are generally employed by industrial or government laboratories as either physicists or engineers. Some are hired as teachers by high schools and by two-year colleges. Holders of the PhD in physics will generally be hired as research and development physicists by industrial or government laboratories and as professors in universities (though usually only following an appointment as a postdoctoral fellow for one to three years).

Additional Information

Regularly updated information about Physics Department activities and programs may be obtained via the Web at:
http://www.physics.usu.edu/.

Physics Courses (Phyx)

Phyx 1000 (BPS). Introductory Astronomy. Exploration of solar system and universe. Laws of motion, fundamental interactions, structure of matter, electromagnetic radiation, and conceptual models of celestial motions. Conceptual and quantitative homework problems and exams, along with writing assignments and observation reports, are required. Facility with high school mathematics is expected. (3 cr)

Phyx 1020 (BPS). Energy. Study of energy resources, utilization, conversion, and conservation, including energy balance and flow in biological and geological systems. Social impacts of energy resource development, including public policy and planning. Prerequisites: At least one university-level mathematics or statistics course, and completion of computer and information literacy examination. (3 cr)

Phyx 1030 (BPS). Intelligent Life in the Universe. Study of the likelihood of extraterrestrial intelligence and its probable locations. Nature and evolution of life on Earth, as well as stellar evolution and planetary environments. Discussion of psychology of UFO phenomena. Prerequisites: At least one university-level mathematics or statistics course, and completion of computer and information literacy examination. (3 cr)

Phyx 1040. From Atoms to Ants. Examines structure and organization of matter, from the small to the large, and inquires into how such seemingly nonphysical phenomena as living, social, and mental activity may be related to the behavior of the atom. Extensive use of computer simulations to explore aspects of the material. Knowledge of programming not required. Cannot be taken for University Studies credit. Prerequisites: At least one university-level mathematics or statistics course, and completion of computer and information literacy examination. (3 cr)

Phyx 1100 (BPS). Great Ideas in Physics. Descriptive introduction to the principles underlying contemporary physics. Great ideas will include relativity and quantum mechanics and such consequences and applications as the twin paradox, black holes, nuclear energy, magnetic imaging, lasers, superconductivity, and the paradox of Schrodinger's cat. Facility with high school algebra is expected. (3 cr)

Phyx 1200 (BPS). Introduction to Physics by Hands-on Exploration. Explores structure of matter, electricity and magnetism, light, and sound through hands-on, inquiry-based activities. Facility with high school algebra is expected. Required laboratory. (4 cr)

Phyx 1800 (BPS). Physics of Technology. Overview of the classical physics on which industrial technology is based. Elements of kinematics, forces, energy, momentum, thermodynamics, electric and magnetic fields, waves, and optics. Required laboratory. Prerequisites: Math 1050 and 1060. (4 cr)

Phyx 2110. The Physics of Living Systems I. Study of kinematics and dynamics of particles and systems of particles. Introduction to Newton's Laws of motion, momentum and energy conservation, rotations, and thermodynamics, with applications in biology and biotechnology. Required recitation and lab. Prerequisite: Math 1100 or 1210. (4 cr)

Phyx 2120 (BPS). The Physics of Living Systems II. Introduction to electromagnetism, optics, and quantum phenomena—including the microscopic structure of matter, with applications in biology and biotechnology. Required recitation and lab. Prerequisite: Math 1100 or 1210, Phyx 2110. (4 cr)

Phyx 2200. Elements of Mechanics. Calculus-based introduction to particle mechanics. Kinematics, Newton's laws of motion, momentum, work and energy, and angular momentum. Required recitation and lab. Prerequisite: Math 1210. (2 cr)

Phyx 2210 (QI). General Physics—Science and Engineering I. Calculus-based introduction to Newton's Laws of motion, momentum and energy conservation, rotations, oscillations, and thermodynamics, with applications in the physical sciences and technology. Required recitation and lab. Prerequisite: Math 1210. (4 cr)

Phyx 2220 (QI). General Physics—Science and Engineering II. Calculus-based introduction to electromagnetism, waves, optics, and modern physics, with applications in the physical sciences and technology. Required recitation and lab. Prerequisites: Math 1210; Phyx 2200 or 2210, *or* a minimum score of 4 on the AP B exam, *or* a minimum score of 3 on the AP C (mechanics) exam. (4 cr)

Phyx 2500. Introduction to Computer Methods in Physics. Introduction to computer assistance in physics. Topics include: (1) use of numerical, graphical, and symbolic manipulation software to solve physics problems; and (2) interfacing computers to instrumentation for control and data acquisition. Prerequisite: Phyx 2110 or 2210 or 2220. (2 cr)

Phyx 2710. Introductory Modern Physics. Overview of modern physics at the intermediate level. Focuses on principles and applications of relativity and quantum mechanics, including a discussion of atomic, solid state, and particle physics. Prerequisites: Math 1220, Phyx 2120 or 2220. (3 cr)

Phyx 3010 (QI, DSC). Space Exploration from Earth to the Solar System. Comparative introduction to the Earth and other planets in our solar system, including geological structure and atmosphere. Emphasis on space exploration methods, including spacecraft and detection instrumentation. Examines latest results of Mars missions, Jupiter and Saturn exploration, etc. Prerequisite: Completion of quantitative literacy and physical sciences breadth. (3 cr)

Phyx 3020 (DSC). Great Scientists. Lives and work of men and women responsible for scientific revolution: Maxwell (loved children), Einstein (despised authority), Curie (suffered discrimination against women), Schrodinger (fled from Hitler), Watson and Crick (the DNA story), Feynman (lock picker), Rubin (as a young girl built her own telescope), and others. Prerequisite: USU 1350. (3 cr)

Phyx 3030 (QI, DSC). The Universe. Study of properties and origin of the universe, based on Einstein's theory of gravity. Topics include curved space-time; black holes, white holes, and worm holes; the big bang; multiple universes; and the births of stars, galaxies, heavy atoms, and planets. Prerequisite: Completion of quantitative literacy and Phyx 1000. (3 cr)

Phyx 3040 (QI). Space Weather—Dangers to the High-Tech World. Space weather can be as destructive to high technology as ordinary weather is to property and crops. Examines increasing vulnerability of society to events in space resulting from changes on the Sun and from human activity. Explores how we learn about space weather with satellites, radars, lidars, and numerical models. Prerequisite: Completion of quantitative literacy and physical sciences breadth. (3 cr)

Phyx 3500. Topics in Physics (Topic). Introduces and explores issues in contemporary physics at intermediate undergraduate level. Focuses on phenomena and experimental methods. Prerequisite: Phyx 2710. (1-3 cr) ®

Phyx 3550. Intermediate Classical Mechanics. Newton's laws of motion, accelerated reference frames, work and energy, systems of particles, rigid body rotation, central force problem, and harmonic oscillations. Prerequisites: Phyx 2710, Math 2210; Math 2250 (may be taken concurrently). (3 cr)

Phyx 3600. Intermediate Electromagnetism. Electrostatics, electric potential, current, magnetostatics, induction, AC curcuits, Maxwell's equations, and electromagnetic waves. Prerequisites: Phyx 2710, Math 2210; Math 2250 (may be taken concurrently). (3 cr)

Phyx 3650. Optics. Geometric optics, interference, diffraction, aberration, polarization, and topics in contemporary optics. Prerequisite: Phyx 2710. (3 cr)

Phyx 3700. Thermal Physics. Rigorous treatment of laws of thermodynamics and statistical mechanics. Concepts of work, temperature, heat, energy, and entropy; and their application to reversible and irreversible processes. Criteria for equilibrium. Prerequisite: Phyx 2710. (3 cr)

Phyx 3750. Foundations of Wave Phenomena. Survey of wave phenomena in physics, with emphasis on application of mathematical techniques to the wave equation, Schrodinger equation, and Maxwell equations. Prerequisites: Phyx 2710, Math 2210; Math 2250 (may be taken concurrently). (3 cr)

Phyx 3870 (CI). Intermediate Laboratory I. Modern experimental techniques, data and error analysis, experimental design, and communication skills. Exercises complement upper-level theory courses, and include some experiments of historical importance. Prerequisite: Phyx 2500. (2 cr)

Phyx 3880 (CI). Intermediate Laboratory II. Continuation of Phyx 3870. Prerequisite: Phyx 3870. (2 cr)

Phyx 3900. Projects in Physics. Individual study pursued under direction of staff member. Prior to registration, arrangements must be made by student with appropriate staff member. (1-3 cr) ®

Phyx 4010 (QI, DSC). Chaos Under Control. Introduction to principles and applications of new sciences of fractals, chaos, and complexity. Importance of describing physical, geological, biological, and natural resource structures with fractals. Practical benefits of understanding and controlling erratic behavior in physical and living systems. Technological consequences of self-organized, adaptive behavior. Prerequisite: Completion of quantitative literacy and physical sciences breadth. (3 cr)

Phyx 4020 (QI, DSC). Nature, Art, and Music. Explores how nature constrains production and appreciation of visual and auditory art. Relevance to art of: physics of sound and light, perspective and observer in relativity and quantum mechanics, symmetry, fractals, chaos, complex adaptive behavior, and self-organization. Prerequisites: Completion of computer and information literacy examination, quantitative literacy, and physical sciences breadth requirements. (3 cr)

Phyx 4250 (CI). Cooperative Work Experience. Planned work experience in industry or national laboratories. A detailed plan and the purpose of the experience must have prior approval. A written report is required. Prerequisite: Phyx 2710. (1-6 cr) ®

Phyx 4550. Advanced Classical Mechanics. Lagrange's equations, Liouville's theorem, continua, Euler's equations, small vibrations, and special relativity. Prerequisites: Phyx 3550, 3750. (3 cr)

Phyx 4600. Advanced Electromagnetism. Potential formulations of electrodynamics, energy and momentum, waves and boundary conditions, waves in dielectrics and conductors, guided waves, dipole radiation, and relativistic electrodynamics. Prerequisites: Phyx 3600, 4550. (3 cr)

Phyx 4700. Quantum Mechanics I. Principles of quantum mechanics, operators in Hilbert space, matrix mechanics, angular momentum, spin, perturbation theory, and applications. Prerequisites: Phyx 3550, 3600, 3750. (3 cr)

Phyx 4710. Quantum Mechanics II. Continuation of Phyx 4700. Prerequisite: Phyx 4700. (3 cr)

Phyx 4900 (CI). Research in Physics. Research experience pursued with faculty mentor. Prior to registration, student must make arrangements with the Physics Department's undergraduate research advisor. Prerequisite: Phyx 2710. (1-3 cr) ®

Phyx 5050. Biophysics of Radiological Health. Brings together sciences relating to nuclear biophysics. Prepares students to be aware of radiological hazards, to safely use radioactive materials, and to comply with relevant laws. Prerequisites: Biol 1210, 1220, Chem 1210, 1220, a physics course, and senior standing. Also taught as Biol 5050. (3 cr)

Phyx 5340. Methods of Theoretical Physics I. Physics applications of vector calculus and differential geometry, group theory, infinite series, complex analysis, differential equations, Sturm-Liouville theory, orthogonal functions, integral equations, and the calculus of variations. (3 cr)

Phyx 5350. Methods of Theoretical Physics II. Continuation of Phyx 5340. Prerequisite: Phyx 5340. (3 cr)

Phyx 5500. Intermediate Topics in Physics (Topic). Explores issues in contemporary physics at the advanced undergraduate and beginning graduate level. (1-3 cr) ®

Phyx 5800. Physics Colloquium. A series of invited lectures on specialized topics in physics and related subjects. (1 cr) ®

Phyx 5870 (CI). Advanced Laboratory. Experimental experience with such modern techniques as scanning tunneling microscopy, LEED, Auger spectroscopy, and Fourier transform infrared spectroscopy. Prerequisite: Phyx 2710. (3 cr)

Phyx 6010. Classical Mechanics I. Lagrange's equations, Hamilton's principle, Hamilton's equations, canonical transformations, Hamilton-Jacobi theory, central forces, noninertial reference frames, rigid body motion, small oscillations, relativistic mechanics, canonical perturbation theory, continuum mechanics. Prerequisite: Phyx 4550 or equivalent. (3 cr)

Phyx 6020. Classical Mechanics II. Continuation of Phyx 6010. Prerequisite: Phyx 6010. (3 cr)

Phyx 6110. Electrodynamics I. Fundamental laws of electrostatics and magnetostatics; dielectric media, Maxwell's equations, time varying fields, and electromagnetic waves. Waveguides and radiation by moving charges. Prerequisite: Phyx 4600 or equivalent. (3 cr)

Phyx 6120. Electrodynamics II. Continuation of Phyx 6110. Prerequisite: Phyx 6110. (3 cr)

Phyx 6210. Quantum Mechanics I. Advanced quantum mechanics stressing the formalism of states and operators in the study of quantum dynamics, angular momentum, symmetry and group theory, perturbation theory and scattering. Prerequisite: Phyx 4710 or equivalent. (3 cr)

Phyx 6220. Quantum Mechanics II. Continuation of Phyx 6210. Prerequisite: Phyx 6210. (3 cr)

Phyx 6240. Space Environment and Engineering. Study of space environment and models used for engineering analysis. Topics include considerations for engineering in the space environment such as plasma interactions, debris, chemical reactions, radiation effects, and thermal issues. Also taught as ECE 6240. (3 cr)

Phyx 6310. Solar-terrestrial Physics I. Study of solar-terrestrial physics, including planetary magnetic fields, the interaction of the sun with planetary properties (magnetic fields and atmospheres), and an overview of ionospheric measurement techniques. Study of the upper atmosphere and the physics occurring in each of the layers and zones, including the equatorial and polar ionosphere. Prerequisite: Phyx 4600 or equivalent. (3 cr)

Phyx 6320. Solar-terrestrial Physics II. Continuation of Phyx 6310. Prerequisite: Phyx 6310. (3 cr)

Phyx 6330. Plasma Physics I. Characteristics of the plasma state and plasma generation; velocity distribution functions, collisions and Boltzmann's equation; wave modes in a plasma; transport theory; plasma devices. Prerequisite: Phyx 4600 or equivalent. (3 cr)

Phyx 6340. Plasma Physics II. Continuation of Phyx 6330. Prerequisite: Phyx 6330. (3 cr)

Phyx 6410. Statistical Mechanics I. Review of thermodynamics. Discussion of foundation of statistical mechanics and applications to ideal classical and quantum gases, blackbody radiation, ideal crystals, interacting classical gases and liquids, phase transitions, and critical phenomena. (3 cr)

Phyx 6420. Statistical Mechanics II. Continuation of Phyx 6410. Prerequisite: Phyx 6410. (3 cr)

Phyx 6530. Solid State Physics I. Development of the modern theory of the solid state. Emphasis placed on understanding the bulk properties of the solids, including

crystal structure, cohesive properties, electronic structure, and lattice dynamics. Explores response to added stimuli, such as electric, magnetic, and optical fields. Prerequisites: Phyx 4600 and 4710; Phyx 6410 (can be taken concurrently). (3 cr)

Phyx 6540. Solid State Physics II. Continuation of Phyx 6530. Prerequisite: Phyx 6530. (3 cr)

Phyx 6550. Physics of Materials I. Application of microscopic (quantum) and macroscopic (classical) physics to study materials properties (e.g., bonding, structure, atomic dynamics, electrical, magnetic, thermal, optical), characterization methods, and a survey of materials. Prerequisites: Phyx 3700, 4710. (3 cr)

Phyx 6560. Physics of Materials II. Continuation of Phyx 6550. Prerequisite: Phyx 6550. (3 cr) (Sp)

Phyx 6910. Relativity I. Foundations of spacetime physics. Survey of the basics of special and general relativity, including kinematics, mechanics, and electrodynamics in flat spacetime, the description of curved spacetime, and the Einstein equations. Exact solutions, applications, tests, and the mathematical techniques of general relativity. Prerequisites: Phyx 6020, 6120. (3 cr)

Phyx 6920. Relativity II. Continuation of Phyx 6910. Prerequisite: Phyx 6910. (3 cr)

Phyx 6930. Quantum Field Theory I. Detailed study of the relativistic quantum description of scalar, spinor, and vector fields in spacetime. Topics include gauge theories, canonical and path integral quantization, and interactions. (3 cr)

Phyx 6940. Quantum Field Theory II. Continuation of Phyx 6930. Prerequisite: Phyx 6930. (3 cr)

Phyx 6970. Thesis Research. Advanced research under guidance of one or more faculty members. (1-10 cr) ®

Phyx 6990. Continuing Graduate Advisement. (1-3 cr) ®

Phyx 7210. Spacecraft Instrumentation. Theory, engineering, and data reduction techniques of spacecraft instrumentation for space science and spacecraft systems. Taught on demand. Also taught as ECE 7210. (3 cr)

Phyx 7500. Advanced Topics in Physics (Topic). Explores issues in contemporary physics at the advanced graduate level. (3 cr) ®

Phyx 7510. Seminar. (1-3 cr) ®

Phyx 7970. Dissertation Research. (1-15 cr) ®

Phyx 7990. Continuing Graduate Advisement. (1-9 cr) ®

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