

PHYSICS AND ASTRONOMY

College of Science and Engineering

Dean: Dr. Carmen Domingo

Department of Physics and Astronomy

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Chair: Dr. Joseph Barranco

Graduate Coordinator: Dr. Susan M. Lea

Program Scope

The Physics and Astronomy Department offers strong undergraduate and graduate programs in physics, astronomy, and astrophysics, which are designed to prepare students for a variety of careers in science, technology, and teaching, as well as for graduate study. The goal is to educate versatile physicists and astronomers who combine a solid knowledge of theory with real-world skills in problem-solving, data acquisition and analysis, and computer-based simulation and analysis. The department specializes in the "hands-on" approach so important in the 21st century. Students at all levels are encouraged to work on a research project under the direction of a faculty supervisor. The projects may involve experimental laboratory work, astronomical observations and data analysis, or theoretical modeling using analytical and computational approaches.

The Bachelor of Arts in Physics is suited for students whose career goals involve the combination of physics with other fields such as engineering, business, or humanities. This program also provides excellent preparation for technical writers, technical salespeople, and laboratory technicians and research assistants.

The Bachelor of Arts in Physics with a Concentration in Astronomy is similar to the B.A. in Physics, but with upper division work concentrated in astronomy. This program also provides excellent preparation for technical writers, as well as observatory or planetarium staff.

The Bachelor of Science in Physics is designed to educate students who plan to pursue further education in physics or related fields (M.S. or Ph.D. programs), or who plan to seek employment as physicists, scientific associates, or technical staff members in industry, national laboratories, or academic laboratories. This program combines the education in physics fundamentals of the B.A. program with additional advanced courses, laboratory, and computer work, and more specialized work in a specialty such as solid state physics, optical physics, or computational physics. Students in this program are strongly encouraged to gain research experience. Graduates should have the fundamental mathematical, scientific, and learning skills to enable them to be lifelong learners who can rapidly master new scientific and technical developments.

The Bachelor of Science in Physics with a Concentration in Astrophysics is similar to the B.S. in Physics program, but with significant upper-division work in astronomy, as appropriate for students planning employment or graduate study in the area of astrophysics. A senior project with a thesis is required.

The Bachelor of Science in Physics with a Concentration in Physics for Teaching is designed for students interested in high school or

middle school teaching. This program stresses education in physics fundamentals together with laboratory work and direct classroom teaching experience. Elective units enable students to gain a breadth of knowledge in one or more additional subjects important for high-school teachers, e.g., mathematics, general science, or chemistry. Students may also elect to take advantage of the department's single subject matter program in physics to demonstrate their preparedness to enter a credential program to complete their training as teachers.

A satisfactory score on an exit examination is required for all Bachelor's degrees.

A Minor in Physics and a Minor in Astronomy are available for students desiring a coherent program in physics or astronomy but one not as extensive as the B.A. It provides an excellent background for prospective secondary school teachers who wish to teach in physics or astronomy as well as in their major area, or for engineers who want additional depth in areas such as solid-state physics or optical physics.

The goal of the Master of Science in Physics is to provide a solid, in-depth background in theoretical and experimental physics, appropriate for students pursuing further education in the field via Ph.D. programs in physics, astronomy, or certain engineering fields, or for those seeking employment as physicists/astronomers in physics/astronomy-related jobs and professions; e.g., as technical associates, laboratory physicists, physics or astronomy data analyzers, engineers, or in education as instructors in community colleges. This program combines advanced education in core physics topics with additional advanced courses, laboratory and computer work, and more concentrated work in a specialty such as solid-state physics, particle physics, quantum optics, astrophysics, or computational physics. Students in this program are strongly encouraged to gain research experience.

The Master of Science in Physics with a concentration in Astronomy offers a program that is more closely tailored to students interested in careers in astronomy teaching and outreach, or employment in astronomical observatories and laboratories. It is also suitable for those seeking entry into Ph.D. programs in astronomy.

Professor

ZHIGANG CHEN (1998), *Professor of Physics*; B.S. (1985), Yanzhou Teacher's College (PRC); M.S. (1988), University of Science and Technology of China; Ph.D. (1995), Bryn Mawr College; Postdoctoral Research Associate, Princeton University.

KIMBERLY A. COBLE (2016), *Professor of Physics and Astronomy*; B.A. (1993), University of Pennsylvania; M.S. (1994), Ph.D. (1999), University of Chicago.

ADRIENNE COOL (1996), *Professor of Physics and Astronomy*; B.S. (1984), Yale College; M.S. (1986), Columbia University; Ph.D. (1994), Harvard University.

MAARTEN GOLTERMAN (2001), *Professor of Physics*; Doctoraal Examen (1983), University of Utrecht; Ph.D., (1986), University of Amsterdam.

JEFFREY P. GREENSITE (1984), *Professor of Physics*; B.S. (1972), University of California, San Diego; Ph.D. (1980), University of California, Santa Cruz.

RONALD MARZKE (2000), *Professor of Physics and Astronomy*; B.S. (1987), Arizona State University; M.A. (1988), Ph.D. (1994), Harvard University.

BARBARA J. NEUHAUSER (1986), *Professor of Physics*; B.S. (1969), Purdue University; M.S. (1970), Stanford University; Ph.D. (1985), Stanford University.

Associate Professor

JOSEPH A. BARRANCO (2007), *Associate Professor of Physics and Astronomy*; A.B. (1993), Harvard University; Ph.D., (2004), University of California, Berkeley.

WEINING MAN (2008), *Associate Professor of Physics and Astronomy*; B.S. (1997), Jilin University; M.S. (2000), Jilin University; Ph.D. (2005) Princeton University.

HUIZHONG XU (2016), *Associate Professor of Physics and Astronomy*; B.S. (1997), Fudan University; M.A. (2000), City College of New York; Ph.D. (2004), University of Maryland, College Park.

Assistant Professor

KRISTAN JENSEN (2015), *Assistant Professor of Physics*; B.S. (2005), University of Puget Sound; Ph.D. (2010), University of Washington.

AKM NEWAZ (2014), *Assistant Professor of Physics and Astronomy*; B.Sc. (1998), Dhaka University; M.A. (2003), Ph.D. (2006), State University of New York at Stony Brook.

Adjunct Professor

MARY BARSONY (2003), *Adjunct Professor of Physics and Astronomy*; B.A. (1976), University of California Berkeley; S.B. (1982), Massachusetts Institute of Technology; M.S. (1984), Ph.D. (1989) California Institute of Technology

DEBRA FISCHER (2003), *Adjunct Professor of Physics and Astronomy*; B.S. (1975), University of Iowa; M.S. (1992), San Francisco State University; Ph.D. (1998), University of California, Santa Cruz.

Adjunct Assistant Professor

CHRIS MCCARTHY (2005), *Adjunct Assistant Professor of Physics and Astronomy*; B.A. (1990), University of California, Berkeley; M.S. (1995), San Francisco State University; M.S. (1997), Ph.D. (2001), University of California, Berkeley.

Lecturers

Bland, Caudy, Dhakal, Digel, Fielder, Tennant

Majors

- [Bachelor of Arts in Physics](#)
- [Bachelor of Arts in Physics: Concentration in Astronomy](#)
- [Bachelor of Science in Physics](#)
- [Bachelor of Science in Physics: Concentration in Astrophysics](#)
- [Bachelor of Science in Physics: Concentration in Physics for Teaching](#)

Minors

- [Minor in Astronomy](#)
- [Minor in Physics](#)

Masters

- [Master of Science in Physics](#)
- [Master of Science in Physics: Concentration in Astronomy](#)

Astronomy

ASTR 115 Introduction to Astronomy (Units: 3)

Prerequisite: Category I or II placement for QR/Math, or completion of GE Area B4, or MATH 197.

Introduction to topics in astronomy including Stonehenge, the solar system, the sun, stars, and stellar evolution, pulsars, black holes, nebulae; galaxies, quasars, the big bang, the expanding universe, and the search for extraterrestrial life. Includes the opportunity for telescopic observation.

Course Attributes:

- B1: Physical Science

ASTR 116 Astronomy Laboratory (Unit: 1)

Prerequisite: ASTR 115 (may be taken concurrently).

Fundamentals of astronomical observation including optics and spectroscopy. Planetarium exploration of the stars, sun, and moon. Opportunity for telescopic observation. Laboratory.

Course Attributes:

- B3: Lab Science

ASTR 300 Stars, Planets, and the Milky Way (Units: 3)

Prerequisite: PHYS 220 or PHYS 111 with a grade of C- or better.

Quantitative study of stars, stellar evolution, and the Milky Way; emphasis on the observational basis of our knowledge of the Galaxy's structure and contents. Application of Newton's laws to exoplanets, determination of stellar masses, and evidence for dark matter. (Plus-minus letter grade only)

ASTR 301 Observational Astronomy Laboratory (Units: 2)

Prerequisites: ASTR 115 or ASTR 300 and PHYS 220 or PHYS 111 with grades of C- or better.

Principles and practices of astronomical observation including telescope and detector design and operation, coordinate and magnitude systems, and the collection, analysis, and presentation of astronomical data. Lecture, 1 unit; laboratory, 1 unit.

ASTR 340GW The Big Bang - GEAR (Units: 3)

Prerequisites: GE Area A2, PHYS 320 or equivalent with a grade of C- or better.

Introduction to cosmology from earlier human conceptions of the universe through the hot Big Bang and inflation. Early universe, nucleosynthesis, dark matter, dark energy, photon and neutrino backgrounds, and observational tests of cosmology. (ABC/NC grading only)

(This course is offered as ASTR 340GW and PHYS 340GW. Students may not repeat the course under an alternate prefix.)

Course Attributes:

- Graduation Writing Assessment

ASTR 341 Planetarium Training (Unit: 1)

Prerequisites: ASTR 115 and ASTR 116; consent of the instructor.

Planetarium operation and understanding of the night sky. Speaking and writing for public and education programs. Activity.

ASTR 400 Stellar Astrophysics (Units: 3)

Prerequisite for ASTR 700: Graduate standing or consent of the instructor.

Prerequisites for ASTR 400: Upper-division standing; CSC 309, MATH 245 or MATH 376, and PHYS 320 all with grades of C- or better; GPA of 3.0 or higher; or consent of the instructor.

Introduction to stellar astrophysics: the birth, life, and death of stars, stellar atmospheres and spectra, stellar interiors, energy generation and transport, star formation, stellar evolution and death, the Solar Cycle and the Sun-Earth connection.

(ASTR 700/ASTR 400 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

ASTR 405 Exoplanetary Science (Units: 3)

Prerequisites: ASTR 115, PHYS 220, and PHYS 330; or consent of the instructor.

Study of extra-solar planets including history, detection methods, planet formation, and exoplanetary atmospheres. Exploration of statistics of exoplanetary systems, habitability, and placing the Solar System in a larger context.

ASTR 470 Observational Techniques in Astronomy (Units: 3)

Prerequisites: ASTR 300; ASTR 301 recommended; CSC 309 strongly recommended; all with grades of C- or better.

Astronomical instrumentation and data analysis with a focus on statistical analysis, CCD photometry, spectroscopy, image processing, and instrument design. Lecture, 2 unit; laboratory, 1 unit.

[Formerly paired with ASTR 770. Students who complete the course at one level may not repeat the course at the other level.]

ASTR 498 Astronomy Research Literature (Units: 2)

Prerequisite for ASTR 798: Graduate standing or consent of the instructor.

Prerequisites for ASTR 498: Upper-division standing; ASTR 300 and PHYS 320 with grades of C- or better; GPA of 3.0 or higher; or consent of the instructor.

Critical reading and analysis of current literature in astronomy and astrophysics.

(ASTR 798/ASTR 498 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

ASTR 685 Projects in the Teaching of Astronomy (Unit: 1)

Prerequisites: ASTR 301 or ASTR 470 with a grade of B or better; consent of the instructor.

Methods for effective student teaching in the SF State Observatory and/or Planetarium. Leading of Observatory Open Nights and the development and/or presentation of Planetarium shows. May be repeated for a total of 3 units. (Students may earn a maximum of 4 units toward the baccalaureate degree for any course(s) numbered 685 regardless of discipline.)

ASTR 697 Senior Project (Units: 1-3)

Prerequisite: Senior standing.

Observational or theoretical projects under the direction of department faculty. A written report of the work accomplished is required. May be repeated for a total of 6 units.

ASTR 699 Independent Study (Units: 1-3)

Prerequisites: Advanced Astronomy and Astrophysics majors and minors; approval of the department and consent of the instructor.

Special study in the laboratory, field, or library under the direction of a faculty member. The student must present a written report of the work accomplished to the faculty member and the department. May be repeated for a maximum of 12 units.

ASTR 700 Stellar Astrophysics (Units: 3)

Prerequisite for ASTR 700: Graduate standing or consent of the instructor.

Prerequisites for ASTR 400: Upper-division standing; CSC 309, MATH 245 or MATH 376, and PHYS 320 all with grades of C- or better; GPA of 3.0 or higher; or consent of the instructor.

Introduction to stellar astrophysics: the birth, life, and death of stars, stellar atmospheres and spectra, stellar interiors, energy generation and transport, star formation, stellar evolution and death, the Solar Cycle and the Sun-Earth connection.

(ASTR 700/ASTR 400 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

ASTR 722 Radiative Processes and Gas Dynamics in Astrophysics (Units: 3)

Prerequisites: Graduate standing; ASTR 400, PHYS 370, PHYS 430, and PHYS 460 or equivalents; PHYS 785 recommended.

Examination of radiative transfer, bremsstrahlung, Compton scattering, and synchrotron radiation, fluid dynamics, and astrophysical shocks. Applications may include accretion, star formation, galaxy formation, star and galaxy clusters, active galactic nuclei, jets, and cosmic ray acceleration.

ASTR 742 Galaxies and Cosmology (Units: 3)

Prerequisites: ASTR 300, PHYS 370, and PHYS 430 or equivalents; ASTR 400 or equivalent recommended.

Formation and evolution of galaxies and large-scale structure. Models of hierarchical structure formation in a universe dominated by dark matter. Observational constraints from the discovery of the expansion of the universe to ongoing experiments probing the nature of dark energy.

ASTR 770 Observational Techniques in Astronomy Research (Units: 3)

Prerequisites: CSC 309 or equivalent with a grade of B- or better and ASTR 400 or ASTR 700 or equivalent.

Astronomical photometry, spectroscopy, and astrometry in the context of research. Statistical analysis, observational research program design, and proposal writing. Lecture, 2 unit; laboratory, 1 unit. (Plus-minus letter grade only) [Formerly paired with ASTR 470. May not repeat the course at a different level.]

ASTR 798 Astronomy Research Literature (Units: 2)

Prerequisite for ASTR 798: Graduate standing or consent of the instructor.

Prerequisites for ASTR 498: Upper-division standing; ASTR 300 and PHYS 320 with grades of C- or better; GPA of 3.0 or higher; or consent of the instructor.

Critical reading and analysis of current literature in astronomy and astrophysics.

(ASTR 798/ASTR 498 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

Physics

PHYS 101 Conceptual Physics (Units: 3)

Prerequisites: Category I or II placement for QR/Math, or completion of GE Area B4, or MATH 197.

Conceptual introduction to Newton's Laws of Motion, properties of matter and energy, heat, sound, light, electricity, magnetism, and atoms.

Course Attributes:

- B1: Physical Science

PHYS 102 Conceptual Physics Laboratory (Unit: 1)

Prerequisite: Concurrent enrollment in PHYS 101.

Laboratory exercises in basic physics.

Course Attributes:

- B3: Lab Science

PHYS 111 General Physics I (Units: 3)

Prerequisites: MATH 198 or MATH 199 or equivalent with a grade of C-minus or higher. Concurrent enrollment in PHYS 112 required. If pre-calculus was completed in high school, the online Math Preparation for Physics mini-course is required; see the Department of Physics & Astronomy website for details.

Introduction to mechanics, waves, sound, fluids, thermodynamics, with applications to biology, life, and health sciences.

Course Attributes:

- B1: Physical Science

PHYS 112 General Physics I Laboratory (Unit: 1)

Prerequisite: Concurrent enrollment in PHYS 111.

Mechanics, heat, and sound. Extra fee required.

Course Attributes:

- B3: Lab Science

PHYS 121 General Physics II (Units: 3)

Prerequisites: PHYS 111; concurrent enrollment in PHYS 122.

Light, electricity, magnetism, atoms, and modern physics.

PHYS 122 General Physics II Laboratory (Unit: 1)

Prerequisite: Concurrent enrollment in PHYS 121.

Light, electricity, magnetism, atoms, and modern physics. Extra fee required.

PHYS 220 General Physics with Calculus I (Units: 3)

Prerequisites: High school physics or equivalent; satisfactory score on physics placement examination; MATH 226 with a grade of C or better; concurrent enrollment in PHYS 222, MATH 227.

Basic mechanics. Calculus is used in examples and problems. Optional tutorial discussion.

Course Attributes:

- B1: Physical Science

PHYS 222 General Physics with Calculus I Laboratory (Unit: 1)

Prerequisite: Concurrent enrollment in PHYS 220.

Experiments in mechanics. Extra fee required.

Course Attributes:

- B3: Lab Science

PHYS 230 General Physics with Calculus II (Units: 3)

Prerequisites: PHYS 220, MATH 227, with grades of C or better; concurrent enrollment in PHYS 232, MATH 228 recommended.

Introduction to electricity and magnetism. Calculus is used in examples and problems.

PHYS 232 General Physics with Calculus II Laboratory (Unit: 1)

Prerequisite: Concurrent enrollment in PHYS 230.

Experiments in electricity and magnetism. Extra fee required.

PHYS 240 General Physics with Calculus III (Units: 3)

Prerequisites: PHYS 220, MATH 227, with grades of C or better; concurrent enrollment in PHYS 242, MATH 228 recommended; recommended for Physics majors.

Wave motion, optics, and thermodynamics.

PHYS 242 General Physics with Calculus III Laboratory (Unit: 1)

Prerequisite: Concurrent enrollment in PHYS 240.

Experiments in wave motion, optics, and thermodynamics.

PHYS 320 Modern Physics I (Units: 3)

Prerequisites: PHYS 230, PHYS 240, MATH 228, with grades of C or better.

Introduction to special relativity, quantum phenomena, the Bohr model of the hydrogen atom, and the Schrödinger equation.

PHYS 321 Modern Physics Laboratory (Units: 2)

Prerequisite: Concurrent enrollment in PHYS 320.

Experiments on quantum physics and other phenomena of modern physics. Methods of data and error analysis. Classwork, 1 unit; laboratory, 1 unit.

PHYS 325 Modern Physics II (Units: 3)

Prerequisite: PHYS 320 with a grade of C- or better.

Physics of multi-electron atoms including L and S coupling schemes and optical spectra; elementary concepts of nuclear and elementary particle physics; use of four-vectors to analyze particle collisions and decays.

PHYS 330 Analytical Mechanics I (Units: 3)

Prerequisites: PHYS 230, MATH 245 or MATH 376, with grades of C- or better.

Vector analysis, fundamentals of statics, kinematics, and dynamics of rigid bodies and systems of particles.

PHYS 340GW The Big Bang - GVAR (Units: 3)

Prerequisites: GE Area A2, PHYS 320 or equivalent with a grade of C- or better.

Introduction to cosmology from earlier human conceptions of the universe through the hot Big Bang and inflation. Early universe, nucleosynthesis, dark matter, dark energy, photon and neutrino backgrounds, and observational tests of cosmology. (ABC/NC grading only)

(This course is offered as ASTR 340GW and PHYS 340GW. Students may not repeat the course under an alternate prefix.)

Course Attributes:

- Graduation Writing Assessment

PHYS 360 Electricity and Magnetism I (Units: 3)

Prerequisites: PHYS 230, PHYS 330, PHYS 385, with grades of C- or better.

Electrostatics, including boundary-value problems, fields in polarizable media, magnetostatics.

PHYS 370 Thermodynamics and Statistical Mechanics (Units: 3)

Prerequisites: PHYS 240, PHYS 320, MATH 228, with grades of C or better.

Classical thermodynamics, kinetic theory, and elementary statistical mechanics. Applications may include quantum statistics, black-body radiation, paramagnetic spin systems, and low-temperature phenomena.

PHYS 385 Introduction to Theoretical Physics I (Units: 3)

Prerequisites: PHYS 240/PHYS 242 with grades of C- or better; concurrent enrollment in PHYS 330.

Principles of theoretical physics. Theoretical techniques applied throughout mechanics, electricity and magnetism, optics, relativity, quantum mechanics, etc. Applications of vector and tensor spaces, coordinate systems, and group theory.

PHYS 430 Quantum Mechanics I (Units: 3)

Prerequisites: PHYS 320, PHYS 360 (may be taken concurrently), PHYS 385, and MATH 245 or MATH 376, with grades of C- or better.

Postulates of quantum mechanics, one-dimensional problems, barriers and the WKB approximation, angular momentum, and hydrogen atom.

PHYS 431 Quantum Mechanics II (Units: 3)

Prerequisite: PHYS 430 with a grade of C- or better.

Problems in three dimensions, matrix mechanics, spin, application to atomic and molecular physics, perturbation theory, and scattering.

PHYS 440 Computational Physics (Units: 4)

Prerequisites: MATH 245 or MATH 376; PHYS 320; and CSC 210 or CSC 309 or ENGR 213.

Analysis and development of numerical algorithms with a focus on computer simulations of physical systems. Topics may include: finite difference methods for nonlinear ordinary differential equations and chaos theory, N-body gravitational systems and molecular dynamics; numerical linear algebra; Fast Fourier Transforms, finite difference and spectral methods for partial differential equations; Monte Carlo methods for integration, Markov chains, statistical mechanics and spin systems; introduction to parallel programming. Lecture, 3 units; laboratory, 1 unit. (PHYS 740/PHYS 440 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

PHYS 450 Introduction to Solid State Physics (Units: 3)

Prerequisites: PHYS 320, MATH 245 or MATH 376, with grades of C- or better.

Crystal structure, x-ray diffraction, lattice vibrations, models of electrical conductivity; electron energy bands in crystals; electrons and holes in semiconductors.

PHYS 457 Introduction to Analog Electronics (Units: 4)

Prerequisites: PHYS 121 or PHYS 230, MATH 226, with grades of C- or better.

Linear network analysis techniques; phasors; diodes; bipolar junction transistors; field-effect transistors; operational amplifiers. Classwork, 3 units; laboratory, 1 unit.

PHYS 460 Electricity and Magnetism II (Units: 3)

Prerequisite: PHYS 360 with a grade of C- or better.

Maxwell's equations; waves in free space and in dielectrics; reflection and refraction; radiation; special-relativistic transformation of the electromagnetic field.

PHYS 480 Introduction to Optics & Photonics (Units: 3)

Prerequisites: PHYS 230 and PHYS 240, PHYS 320 and PHYS 385 recommended, with grades of C- or better.

Ray optics, including optical fibers and instruments. Wave optics, including interference, diffraction, electromagnetic waves and polarization. Selected topics including beam optics, Fourier optics, photonic-crystal optics, laser basics, holography.

PHYS 490 Physics Project Laboratory (Units: 2)

Prerequisite: PHYS 321 with a grade of C- or better.

Experiments from the fields of atomic, nuclear, solid-state, and optical physics with emphasis on electronic instrumentation and computer-assisted data acquisition. Lecture, 1 unit; laboratory, 1 unit. (Completion of PHYS 490 and PHYS 491 GW with a grade of C or better culminates in the satisfaction of GVAR.) (ABC/NC grading only)

PHYS 491GW Advanced Laboratory II - GVAR (Unit: 1)

Prerequisites: GE Area A2; PHYS 490 with a grade of C or better.

Advanced laboratory work in atomic, nuclear, solid state, and optical physics. Preparation of publication-quality reports and oral presentations on experiments. (ABC/NC grading only)

Course Attributes:

- Graduation Writing Assessment

PHYS 495 Introduction to Apparatus Fabrication (Unit: 1)

Prerequisites: Physics major; PHYS 490 with a grade of C- or better; consent of instructor.

Laboratory work with materials, machine tools (lathe, mill, etc.), and fabrication methods for the production of experimental research apparatus. Safety considerations.

PHYS 685 Instructional Methods in Teaching Physics (Unit: 1)

Prerequisite: Upper-division standing.

Pedagogical strategies and principles of teaching and learning in STEM. Seminar for students in their first Learning Assistant (LA) or Supplemental Instruction (SI) position.

PHYS 686 Experiences in Teaching Physics (Unit: 1)

Prerequisite: Upper-division standing.

Activity practicum for students serving as Learning Assistants (LAs) in STEM courses. LAs will directly assist STEM instructors in facilitating active learning in their classrooms. May be repeated for a total of 6 units.

PHYS 695 Culminating Experience in Physics (Unit: 1)

Prerequisite: Final semester of a Physics degree program.

Preparation of a portfolio of work completed in classes required for the degree. The final examination will be the ETS physics major field test.

PHYS 697 Senior Project (Units: 1-3)

Prerequisites: PHYS 490; consent of faculty adviser.

Participation in experimental or theoretical project under the direction of faculty member. Written report of specific observations and calculations required. May be repeated with consent of advisor.

PHYS 699 Independent Study (Units: 1-3)

Prerequisite: Approval of department and consent of instructor.

Study in the laboratory or library under the direction of a member of the department. For students majoring or minoring in physics. Student must present a detailed written report of the work accomplished to the department. May be repeated for a total of 12 units.

PHYS 701 Classical Mechanics (Units: 3)

Prerequisites: Graduate standing; PHYS 460 (may be taken concurrently), PHYS 785 recommended.

Lagrangian and Hamiltonian mechanics; motion in arbitrary central force potentials; canonical transformation theory; Liouville's theorem; computer visualizations of phase space trajectories and topologies; collisionless Boltzmann equation applied to stellar dynamics; Jeans theorems, orbital anisotropy, and phase space distribution functions.

PHYS 704 Electricity and Magnetism I (Units: 3)

Prerequisites: PHYS 785, PHYS 460, PHYS 701 recommended.

Boundary-value problems in electrostatics, magnetostatics; Maxwell's equations and the causal structure of electrodynamics; plane waves and wave propagation.

PHYS 706 Quantum Mechanics (Units: 3)

Prerequisites: PHYS 701, PHYS 785.

Bound states, collision theory, matrix mechanics, symmetry and groups, perturbation theory.

PHYS 710 Advanced Laboratory Techniques (Units: 3)

Prerequisite: PHYS 490.

Techniques of electronic instrumentation, computerized data acquisition, digital signal processing, and data analysis designed to prepare the student for experimental research work in academic and industrial laboratories. Classwork, 2 units; laboratory, 1 unit.

PHYS 711 Semiconductor Devices and Technology (Units: 3)

Prerequisite: PHYS 450 with a grade of C or better.

Physical principles of semiconductor devices based upon mesostructures. Introduction to integrated circuit fabrication technology structures.

PHYS 712 Physics of Plasmas (Units: 3)

Prerequisites: Graduate standing; PHYS 460; PHYS 701 or PHYS 785 recommended.

Fundamental properties of plasmas. Motion of charged particles in electromagnetic fields. Kinetic theory of plasmas, including the Boltzmann and Vlasov equations. Fluid theory of plasmas, including magnetohydrodynamics. Waves and instabilities. Applications to controlled thermonuclear fusion and space physics.

PHYS 714 Low-Temperature Physics (Units: 3)

Prerequisites: PHYS 360, PHYS 430, with grades of C or better.

Low temperature thermal and electrical behavior of materials; theories of superconductivity and superfluidity; superconducting devices including Josephson junctions, quantum interference devices and cryogenic phonon.

PHYS 715 Lasers and Quantum Optics (Units: 3)

Prerequisites: PHYS 430, PHYS 460.

Atom-field interaction, stimulated emission, dipole oscillations, the ammonia maser, semi-classical laser theory, coherent states, quantum laser theory, Fourier optics, and holographic interferometry.

PHYS 725 Special and General Relativity (Units: 3)

Prerequisites: Graduate standing; PHYS 701 (may be taken concurrently); PHYS 785 recommended.

Tensor formulation of special relativity with astrophysical applications. Riemannian geometry. The Einstein field equations applied to Mercury's orbit, black holes, gravitational lensing, cosmology, and interstellar travel. Computer visualizations of spacetimes and orbits.

PHYS 726 Quantum Field Theory (Units: 3)

Prerequisites: PHYS 430, PHYS 431, PHYS 706.

Relativistic wave equations; quantization of the scalar, Dirac, and Maxwell fields. The LSZ reduction formula for S-matrix elements. Path-Integral evaluation of time-ordered products. Tree-level Feynman diagrams in quantum electrodynamics, and an introduction to non-abelian gauge theory.

PHYS 730 Photonics and Nano Materials (Units: 2)

Prerequisites: Graduate standing or PHYS 230, PHYS 240, PHYS 320, PHYS 360.

Physical principles and cutting-edge research on photonics, nanomaterials, and soft condensed matter physics. (Plus-minus letter grade only)

PHYS 740 Computational Physics (Units: 4)

Prerequisites: MATH 245 or MATH 376; PHYS 320; and CSC 210 or CSC 309 or ENGR 213.

Analysis and development of numerical algorithms with a focus on computer simulations of physical systems. Topics may include: finite difference methods for nonlinear ordinary differential equations and chaos theory, N-body gravitational systems and molecular dynamics; numerical linear algebra; Fast Fourier Transforms, finite difference and spectral methods for partial differential equations; Monte Carlo methods for integration, Markov chains, statistical mechanics and spin systems; introduction to parallel programming. Lecture, 3 units; laboratory, 1 unit. (PHYS 740/PHYS 440 is a paired course offering. Students who complete the course at one level may not repeat the course at the other level.)

PHYS 775 Statistical Physics (Units: 3)

Prerequisites: PHYS 370, MATH 376, PHYS 385.

Statistical methods in physics: probability, phase space, distribution functions, partition functions. Maxwell-Boltzmann, Fermi-Dirac, and Bose-Einstein statistics. Phase transitions, Monte Carlo method, transport theory. (Plus-minus letter grade only)

PHYS 785 Theoretical Physics (Units: 3)

Prerequisites: PHYS 360, PHYS 460 (may be taken concurrently).

Advanced concepts and techniques in mathematics applied to problems in physics. Applications in mechanics, electricity and magnetism, and fluids. (Plus-minus letter grade only)

PHYS 832 Instructional Methods in Physics (Units: 2)

Prerequisite: Graduate standing or consent of the instructor; concurrent GTA appointment.

Instructional methods for the teaching of physics laboratories including the introductory lecture, laboratory safety procedures, supervision of laboratory students, proper handling of equipment and demonstrations, and best practices in maintaining lab logbooks and writing lab reports. May be repeated for a total of 4 units. (CR/NC grading only)

PHYS 885 Projects in Teaching Physics and Astronomy (Units: 3)

Prerequisite: Graduate standing.

Learning experience and pedagogical strategies and principles of teaching and learning physics and/or astronomy. Required of students in their first GTA position. (Plus-minus letter grade only)

PHYS 890 Introduction to Physics Research (Units: 1-3)

Prerequisite: Graduate standing.

Introduction to methods of physics research. May be repeated for a total of 5 units. (CR/NC only)

PHYS 891 Physics Research Design (Units: 1-3)

Prerequisites: Passed Level 1 Written English Proficiency Requirement and have research project approved.

Elements of Physics/Astronomy research proposals: literature review, project significance, and feasibility, materials and methods, budget, data analysis and presentation, statistical significance, reference notation. May be repeated for a total of 4 units.

PHYS 896 Directed Reading in Physics (Units: 1-3)

Prerequisite: Graduate standing.

Readings/tutorials to achieve better understanding of specific topics based on individual student need. Focus on review and integration of core concepts in preparation for the comprehensive oral examination. (Does not count toward MS degree requirements.) (CR/NC only)

PHYS 896EXM Culminating Experience Examination (Units: 0-3)

Prerequisites: Consent of instructor, committee chair, and approval of Advancement to Candidacy (ATC) and Culminating Experience (CE) forms by Graduate Studies. ATC and Proposal for Culminating Experience Requirement forms must be approved by the Graduate Division before registration.

Enrollment in 896EXAM required for students whose culminating experience consists of an examination only. Not for students enrolled in a culminating experience course numbered PHYS 898 (or in some cases, course number PHYS 890 - see program's graduate advisor for further information). (CR/NC, RP)

PHYS 897 Research (Units: 1-3)

Prerequisite: Completed undergraduate major in physics.

Independent and original laboratory investigation under supervision of a staff member. May be repeated. (Plus-minus letter grade, CR/NC, RP)

PHYS 898 Master's Thesis (Units: 3)

Prerequisites: Consent of instructor and approval of Advancement to Candidacy (ATC) and Culminating Experience (CE) forms by Graduate Studies.

Advancement to Candidacy and Proposal for Culminating Experience Requirement forms must be approved by the Graduate Division before registration. (CR/NC grading only)

PHYS 899 Independent Study (Units: 1-3)

Prerequisite: Approval of department and consent of instructor.

Study in the laboratory or library under the direction of a member of the department. For graduate students in physics. The student must present a detailed written report of the work accomplished to the department. May be repeated.