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 Coordinators: Dr. Adrienne Cool (Astronomy) and Dr. Maarten Golterman (Physics)

Mission Statement & Program Scope
The fields of physics & astronomy use the scientific method to investigate the fundamental laws that govern the cosmos and all its contents, from subatomic particles to the cosmic web of galaxies on the largest observable scales in the universe and beyond. The pursuit of science is a human endeavor, and our department welcomes the full spectrum of humanity to contribute their perspectives, passions, and skills to scientific exploration. The mission of San Francisco State University’s Department of Physics & Astronomy is to equip students from all backgrounds with foundational content knowledge in classical mechanics, electricity & magnetism, special & general relativity, thermodynamics & statistical mechanics, quantum mechanics, and astronomy & astrophysics; to provide “hands-on” training in theoretical, experimental, observational, and computational techniques for pure research and industrial and “real-world” applications; to mentor students to embrace an empirical, scientific framework to expand the boundaries of knowledge through novel research, and, ultimately, to create diverse STEM leaders, teachers, and policy-makers ready to tackle the most challenging problems facing society locally and globally.

Our department currently offers the following degrees: B.A. Physics (with and without a concentration in Astronomy), B.S. Physics (with and without concentrations in Astrophysics and Physics for Teaching), and M.S. Physics (with and without a concentration in Astronomy). The B.A. degrees are ideal for students who want a strong background in physical science but desire more flexibility to blend their curriculum with other interests. Students with the B.A. degree often pursue careers in teaching, science communication & outreach, pre-medical/dental/health, or business sub-fields in which a rigorous scientific background is beneficial. The B.S. degrees require more in-depth technical training, advanced laboratory experiences, and specialized elective topics. Students with the B.S. degree often pursue science and engineering careers and/or pursue advanced graduate degrees. The B.S. Physics, Concentration in Physics for Teaching allows for a very flexible curriculum that can be combined with Mathematics, Chemistry, or Earth & Climate Sciences to provide breadth across the physical sciences ideal for future K-12 teachers. Our M.S. programs offer the greatest technical depth and usually involve independent research using advanced theoretical, experimental, observational, and computational techniques.

Program Learning Outcomes
Graduates with degrees in Physics & Astronomy will be able to:

1. Describe universal physical principles in classical mechanics, electricity & magnetism, special & general relativity, thermodynamics & statistical mechanics, quantum mechanics, astronomy & astrophysics, and relate fundamental conservation principles (conservation of energy, conservation of linear momentum, conservation of angular momentum) to underlying symmetries of nature.

2. Analyze real-world physical systems on Earth and throughout the Universe, develop simplified models of such systems, translate physical principles into the language of mathematics, and then apply the appropriate mathematical tools (vector calculus, linear algebra, differential equations, variational techniques, probability & statistics, numerical & computational methods) to determine a system’s spatiotemporal evolution with an awareness of the limitations of any solutions due to the approximations of the physical models and/or mathematical/computational techniques.

3. Demonstrate proficiency with basic laboratory skills and experimental techniques with electronics, lasers & optical devices, sensors, detectors, microscopes, and telescopes, always with appropriate safety practices (especially with respect to lasers, chemicals, radioactive materials).

4. Articulate and apply the “scientific method,” the empirical, iterative method of acquiring new knowledge through developing models to explain observations of the natural world, formulating testable hypotheses, designing and executing experimental, computational, and theoretical investigations to test predictions, analyzing data with appropriate statistics and attention to uncertainties, ascertaining consistency with existing theories, and sharing results with the broader scientific community for confirmation and validation.

5. Demonstrate writing, speaking, and visual data presentation skills to effectively communicate science at the appropriate level of sophistication for the relevant target audience (e.g., instructors, students, scientists, public-at-large, policy-makers).

6. Develop the social and communication skills to effectively participate in diverse scientific teams, including those that are multidisciplinary and/or interdisciplinary, and appreciate that the pursuit of science is a human endeavor and that progress is best made when the full spectrum of humanity is encouraged to participate and share their perspectives, passions, and skills.

7. Engage local, state, national & global communities to address current and emerging scientific and technological challenges in equitable and environmentally sustainable ways.

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

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.


ADRIENNE COOL (1996), Professor of Physics; 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. GREENSITES (1984), Professor of Physics; B.S. (1972), University of California, San Diego; Ph.D. (1980), University of California, Santa Cruz.


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

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

Associate Professor

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

Assistant Professor


CHARLI SAKARI (2019), Assistant Professor of Physics and Astronomy; B.A. (2009), Whitman College; Ph.D. (2014), University of Victoria.

Adjunct Professor


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

Salma Begum, Sarah Deveny, Jeanne Digel, Jessica Fielder, Violeta Grigorescu, Arefa Hossain, Katie Kooistra, Alexandra Liguori, Andrew Sturner, Elaine Tennant, Aaron White, David Yee

Majors

- Bachelor of Arts in Physics (http://bulletin.sfsu.edu/colleges/science-engineering/physics-astronomy/ba-physics/)
- Bachelor of Arts in Physics: Concentration in Astronomy (http://bulletin.sfsu.edu/colleges/science-engineering/physics-astronomy/ba-physics-concentration-astronomy/)
- Bachelor of Science in Physics (http://bulletin.sfsu.edu/colleges/science-engineering/physics-astronomy-bs-physics/)
- Bachelor of Science in Physics: Concentration in Astrophysics (http://bulletin.sfsu.edu/colleges/science-engineering/physics-astronomy-bs-physics-concentration-astrophysics/)
- Bachelor of Science in Physics: Concentration in Physics for Teaching (http://bulletin.sfsu.edu/colleges/science-engineering/physics-astronomy-bs-physics-concentration-physics-for-teaching/)

Minors

- Minor in Astronomy (http://bulletin.sfsu.edu/colleges/science-engineering/physics-astronomy/minor-astronomy/)
- Minor in Physics (http://bulletin.sfsu.edu/colleges/science-engineering/physics-astronomy/minor-physics/)

Masters

- Master of Science in Physics (http://bulletin.sfsu.edu/colleges/science-engineering/physics-astronomy/ms-physics/)
- Master of Science in Physics: Concentration in Astronomy (http://bulletin.sfsu.edu/colleges/science-engineering/physics-astronomy/ms-physics-concentration-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 121 or PHYS 240 (may be taken concurrently).

Quantitative study of stars, stellar evolution, and the Milky Way with an 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.

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 - GWAR (Units: 3)
Prerequisites: GE Area A2 and PHYS 320 with a grade of C- or better.

Introduction to cosmology from earlier human conceptions of the universe through the hot Big Bang. Topics include: measuring space and time, the cosmic distance ladder, gravitation, general relativity and the curvature of spacetime, expansion of the universe, large scale structure, the early universe, the cosmic microwave background, nucleosynthesis, dark matter, dark energy and the ultimate fate of the universe. Emphasis will be on how we know what we know about the universe, including observational and experimental evidence. (ABC/NC grading only)

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 permission of the instructor.
Prerequisites for ASTR 400: Upper-division standing; ASTR 300, CSC 309, MATH 245 or MATH 376, and PHYS 320, all with grades of C- or better; GPA of 3.0 or higher; or permission 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 permission of the instructor.
Prerequisites for ASTR 400: Upper-division standing; ASTR 300, CSC 309, MATH 245 or MATH 376, and PHYS 320, all with grades of C- or better; GPA of 3.0 or higher; or permission 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 in Astrophysics (Units: 3)
Prerequisite: Graduate standing or permission of instructor.

Fundamentals of radiative transfer; basic theory of radiation fields; radiation from moving charges; relativistic covariance and kinematics; bremsstrahlung; synchrotron radiation; Compton scattering; plasma effects; atomic structure; radiative transitions; molecular structure. Applications include stellar and planetary atmospheres, circumstellar disks, the interstellar medium, galaxies, active galactic nuclei, and the intergalactic medium.

ASTR 742 Galaxies and Cosmology (Units: 3)
Prerequisites: Graduate standing or permission of the instructor.

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: Graduate standing; ASTR 700; or permission of the instructor.

Astronomical photometry, spectroscopy, and astrometry in the context of research. Statistical analysis, observational research program design, and proposal writing. Seminar, 2 units; laboratory, 1 unit.
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.)

ASTR 895 Culminating Project (Units: 3)
Prerequisites: Advancement to Candidacy (ATC) and Proposal for Culminating Experience (PCE) forms must be approved by the Division of Graduate Studies before registration.
Independent and original culminating project in astronomy and astrophysics under faculty supervision leading to written project report and oral defense of the project. Culminating projects could include: development of new teaching/curricular modules, portfolios of science writing/journalism, internships in science museums/planetaria or industrial or national research labs, development of technical reports/manuals for new scientific instruments, etc. (CR/NC, RP)

ASTR 896 Directed Reading in Astronomy and Astrophysics (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 grading only)

ASTR 896EXM Culminating Experience Examination (Units: 0-3)
Prerequisites: Advancement to Candidacy (ATC) and Proposal for Culminating Experience (PCE) forms must be approved by the Division of Graduate Studies before registration.
Comprehensive oral examination on core topics in astronomy and astrophysics. (CR/NC, RP)

ASTR 897 Research (Units: 1-3)
Prerequisite: Graduate standing.
Independent research under the supervision of faculty. May be repeated. (Plus-minus letter grade, CR/NC, RP)

ASTR 898 Master’s Thesis (Units: 3)
Prerequisites: Advancement to Candidacy (ATC) and Proposal for Culminating Experience (PCE) forms must be approved by the Division of Graduate Studies before registration.
Independent and original experimental, observational, theoretical, or computational research in astronomy and astrophysics under faculty supervision leading to written Master’s Thesis and oral defense of thesis. (CR/NC, RP)

ASTR 899 Independent Study (Units: 1-3)
Prerequisite: Graduate standing.
Independent study under the supervision of faculty. May be repeated. (Plus-minus letter grade, CR/NC, RP)

Physics

PHYS 101 Conceptual Physics (Units: 3)
Prerequisite: 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 (Units: 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 (Units: 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 (Units: 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 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 491GW with a grade of C or better culminates in the satisfaction of GWAR.) (ABC/NC grading only)

PHYS 491GW Advanced Laboratory II - GWAR (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 majors; PHYS 490 with a grade of C- or better; consent of the 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)
Prerequisite: PHYS 490; consent of the 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 the 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)
Prerequisite: Graduate standing or permission of the instructor.

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 Electrodynamics (Units: 3)
Prerequisites: Graduate standing or permission of the instructor.

PHYS 785 strongly recommended.

Boundary-value problems in electrostatics; multipoles, electrostatics of macroscopic media, dielectrics; magnetostatics, Faraday’s Law, quasi-static fields; Maxwell equations, macroscopic electromagnetism, conservation laws; plane electromagnetic waves and wave propagation.

PHYS 706 Quantum Mechanics (Units: 3)
Prerequisites: Graduate standing or permission of the instructor.

PHYS 785 strongly recommended.

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.

PHYS 712 Physics of Plasmas (Units: 3)
Prerequisites: Graduate standing; 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: 3)
Prerequisites: PHYS 320 and PHYS 360 or consent of the instructor. Non-Physics majors should consult with the instructor.
Introduction to light-matter interactions in nanostructures, including: basic properties of electromagnetic waves and quantum particles, wave optics and wave mechanics, electrons in periodic structures and quantum confinement effects, semiconductor nanocrystals (quantum dots), nanophasmons, multilayer structures, metamaterials, photonic crystals, photonic circuitry. Applications to microscopy, optical antennas, devices for opto-mechanics, energy conversion, biomedicine, nanophotonics for communication and quantum information science.

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 Mechanics (Units: 3)
Prerequisite: Graduate standing or permission of the instructor.

PHYS 785 Theoretical Physics (Units: 3)
Prerequisite: Graduate standing or permission of the instructor.
Advanced concepts and techniques in mathematics applied to problems in physics. Applications in mechanics, electricity and magnetism, and fluids.

PHYS 825 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 832 Instructional Methods in Physics (Units: 2)
Prerequisites: 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 Inclusive Pedagogy for the Physical Sciences (Units: 3)
Prerequisite: Graduate standing or consent of the instructor.
Development and refinement of effective, evidence-based, student-centered teaching strategies for the physical sciences with a special focus on inclusive practices to foster equity. Activities include discussion, reflection, peer observations, and projects.

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 895 Culminating Project (Units: 3)
Prerequisites: Advancement to Candidacy (ATC) and Proposal for Culminating Experience (PCE) forms must be approved by the Division of Graduate Studies before registration.
Independent and original culminating project in physics under faculty supervision leading to written project report and oral defense of the project. Culminating projects could include: development of new teaching/curricular modules, portfolios of science writing/journalism, internships in science museums/planetaria or industrial or national research labs, development of technical reports/manuals for new scientific instruments, etc. (CR/NC, RP)

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 the 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 the 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, RP 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.