DEPARTMENT OF PHYSICS AND ASTRONOMY (GRAD)

The Department of Physics and Astronomy offers graduate work leading to the degrees of master of science and doctor of philosophy.

The active fields of research are biophysics, medical physics, condensed-matter physics, materials physics, nanotechnology, nuclear physics, neutrino physics and nuclear astrophysics, quantum field theory, theoretical particle physics, general relativity and gravitation, extragalactic and stellar astronomy, and astrophysics. Students can also work in the UNC–Chapel Hill biophysics program. The graduate courses are designed to give students a broad foundation and to introduce them to the special fields in which the research interests of the department lie.

The general regulations of The Graduate School govern the work for the degrees of master of science and doctor of philosophy. To begin a graduate program in physics or astrophysics, the student should have completed most of the requirements for the degree of bachelor of science with a major in physics at the University, or their equivalent elsewhere. The minimum prerequisite for graduate study consists of the basic undergraduate courses:

Code	Title	Hours
PHYS 118	Introductory Calculus-based Mechanics and Relativity [H, F]	4
PHYS 119	Introductory Calculus-based Electromagnetism and Quanta [H, F]	4
PHYS 128L	Modern Physics Laboratory	1
PHYS 311	Electromagnetism I	3
PHYS 401	Mechanics I	3
PHYS 412	Electromagnetism II	3
PHYS 421	Introduction to Quantum Mechanics	3
PHYS 441	Thermal Physics	3
PHYS 521	Applications of Quantum Mechanics	3
Together with the following courses:		
MATH 232	Calculus of Functions of One Variable II [H, F]	4
MATH 233	Calculus of Functions of Several Variables [H, F]	4
MATH 528	Mathematical Methods for the Physical Sciences I	3
Total Hours		**38**

H Honors version available. An honors course fulfills the same requirements as the nonhonors version of that course. Enrollment and GPA restrictions may apply.

F FY-Launch class sections may be available. A FY-Launch section fulfills the same requirements as a standard section of that course, but also fulfills the FY-SEMINAR/FY-LAUNCH First-Year Foundations requirement. Students can search for FY-Launch sections in ConnectCarolina using the FY-LAUNCH attribute.

Research Interests

Astronomy and Astrophysics

Research includes the formation, structure, and evolution of stars, our Milky Way galaxy, evolution and dynamics of galaxies, gamma ray bursters, cosmology, numerical relativity and sources of gravitational radiation, stellar seismology and quasars, exo-planets, and interstellar medium physics. UNC–Chapel Hill has guaranteed observing time on the 4.1-meter SOAR Telescope in Chile. UNC–Chapel Hill operates a number of smaller robotic telescopes as well and maintains multiple astronomical instrumentation laboratories dedicated to adaptive optics and state-of-the-art spectroscopy.

Biological and Medical Physics

Experimental studies include manipulation and force measurement techniques with applications to DNA, molecular motors, cells, and cilia, and hydration effects in adsorption of biochemicals. There is also a strong focus on the theoretical and experimental translational research in medical imaging technologies, including radiotherapy instruments based on carbon nanotube X-ray emitters such as single-cell irradiation and in vivo micro-CT; optical coherence tomography with nanoparticle molecular imaging agents; and systems-level implementation of tomographic imaging instruments.

Condensed-Matter Physics

Experimental and theoretical studies of nanomaterials. Atomic scale studies of devices and nanoelectromechanical systems, including quantum computation and transport, actuating nanomotors and sensors, amorphous materials, semiconductors, superconductors, the optical properties of solids, charge transport in solids and fluids, epitaxial growth, magnetic materials and heterostructures.

Field Theory, Particle Physics, Cosmology, Gravitation and Relativity

Research includes gauge field theories, quantum chromodynamics, electroweak theory, grand unified theories, string theory, supersymmetry, supergravity, quantum gravity, theoretical cosmology, numerical relativity, gravitational radiation, and relativistic astrophysics.

Materials Science and Materials Physics

Experimental and theoretical research in the design, synthesis, integration, and characterization of novel solid state materials, including nanostructured materials such as quantum dots, carbon nanotubes and nanorods, quasi-crystals, and metallic glass. Applications of novel materials for solar energy, electron field emission, probes and sensors, and data storage. Applications include flat-panel displays, an X-ray system for biomedical imaging, and rechargeable batteries.

Nuclear Physics

Experimental and theoretical work includes neutrino oscillations and neutrino mass measurements, fundamental symmetries and weak interactions in supernovae. The structure and evolution of stars are investigated using nuclear probes. The origin of the elements in the universe is studied using local accelerator facilities. The nature of the nuclear force and properties of few-body systems. Polarized beams of light ions and gamma-rays and polarized 3He target. Applied nuclear physics.

Facilities and Equipment

Research in physics and astronomy is carried out in laboratories on and off the Chapel Hill campus. Within Phillips Hall and Chapman Hall there are several major research laboratories including the "nanomanipulator" (a combination of a scanning electron microscope, an atomic force microscope, and sophisticated visualization graphics); the Keck Laboratory for Atomic Imaging and Manipulation, which includes two transmission electron microscopes; and the Goodman Laboratory for Astronomical Instrumentation. Other facilities include apparatus for

nuclear magnetic resonance studies, scanning probe microscopes, and Raman and optical spectrometers. For synthesis and fabrication, major facilities include molecular beam epitaxy, microwave plasma-enhanced chemical vapor deposition, laser ablation, and photolithography and reactive ion etching. Resources for highly parallel computing are provided by UNC's Information and Technology Services as well as by national centers.

The department is a partner in the Triangle Universities Nuclear Laboratory and plays a major role in experiments using the Laboratory for Experimental Nuclear Astrophysics (LENA), Tandem Accelerator, and the High-Intensity Gamma-Ray Source at the Free Electron Laser facility. UNC–Chapel Hill has an active program in low-background physics at the KURF underground facility near Blacksburg, VA. UNC–Chapel Hill has a 0.6-meter on-campus telescope and is a major partner in the 4.1-meter SOAR Telescope in Chile. The department operates the PROMPT array of robotic telescopes in Chile and manages the SkyNet array of robotic telescopes. Numerous national laboratories, including Oak Ridge, Brookhaven, NIST, Los Alamos, and Argonne, as well as KamLAND, NRAO, NOAO, the Hubble Space Telescope, and the Chandra X-ray Observatory are also vital parts of our research efforts.

Fellowships and Assistantships

Teaching Assistantships (with stipends of $20,500 for nine months) are available to qualified graduate students. Summer employment is usually available. The duties of assistants include supervising laboratory classes in introductory physics or astronomy, supporting the supervision of advanced laboratories, teaching recitation sections, and grading assignments. Graduate School fellowships are available for well-qualified applicants to the department's graduate program. Graduate students can usually be supported in the summer by teaching or research.

Research assistantships are also offered, especially to those who have completed a year or two of graduate work. The stipend is at least $30,000 for the calendar year.

Application forms for admission, including graduate appointments, should be completed online (http://gradschool.unc.edu/admissions/).

The purpose of the graduate program is to educate professional scientists at the Ph.D. level. The training prepares students for careers on university and college faculties; in industrial research and development facilities; in government laboratories and research centers; and in a variety of other scientific and technical venues. Scientific training at this level is achieved through classroom study in the core areas of the discipline common to all subfields of physics and astronomy, as well as in specialized areas at the advanced level. With this foundation, training will continue by engaging in a program of research, in partnership with one or more faculty members, which results in original work of scientific scholarship in the form of a doctoral dissertation. This research may consist of experimental, theoretical, observational, or computational work; or it may combine elements of several or all of these. The general regulations of The Graduate School govern the work for graduate degrees in physics and astronomy. Specific requirements summarized below. Detailed information may be obtained from the department.

A candidate for a Ph.D. degree must complete the following requirements:

1. Pass the doctoral written exam in four of the following seven core courses: PHYS 701, 712, 721, 741, ASTR 711, 712, 719, and completing a research or literature review paper.
2. Pass the teaching seminar (PHYS 510) and the introductory graduate seminar (PHYS 885).
3. Completing course work in four additional electives at a satisfactory level. Generally, only courses numbered 600 or higher count for graduate level course credit.
4. Passing the preliminary oral exam, presenting the thesis prospectus.
5. Acquiring two semesters of teaching experience as TA or equivalent.
6. Writing a Ph.D. thesis and successfully defending it during a final oral examination.

The department does not offer a terminal M.S. degree, but students are encouraged to acquire the M.S. degree (non-thesis option) as an additional milestone during their thesis work. All course work (see above) needs to be completed by the semester in which the M.S. degree is defended.

Professors

Rosa Tamara Branca, Nuclear Spin Hyperpolarization-Magnetic Resonance Imaging and Spectroscopy, Biomedical and Biomolecular Imaging
James Christopher Clemens, Observational Astronomy, Astrophysics, Astronomical Instrumentation
Louise A. Dolan, Theoretical Particle Physics, Quantum Gravity
Joaquín Emiliano Drut, Computational Quantum Many-body Physics
Jonathan H. Engel, Theoretical Nuclear Physics
Adrienne Lynn Erickcek, Theoretical Astrophysics and Cosmology
Charles R. Evans, Gravity, Relativity, Theoretical Astrophysics
Fabian Heitsch, Computational Astrophysics
Reyco Henning, Neutrino Physics, Particle Astrophysics
Christian Iliadis, Experimental Nuclear Astrophysics
Robert Victor Janssens, Experimental Nuclear Physics and Astrophysics
Dmitri V. Khveshchenko, Theoretical Quantum Many-body Physics, Holographic Principle
Nicholas M. Law, Exoplanets, Time-domain Astronomy, Data Science, Astronomical Instrumentation
Rene Lopez, Experimental Condensed Matter Physics
Jianping Lu, Medical Imaging Physics, AI, Nanotechnology, Computational and Condensed Matter Theory
Laurie E. McNeil, Experimental Condensed Matter and Materials Physics
Laura Mersini-Houghton, Theoretical Cosmology
Amy Lynn Oldenburg, Biological and Medical Physics, Biophotonics
Lu-Chang Qin, Materials Science, Nanotechnology
Daniel E. Reichart, Gamma Ray Bursts, Early Universe, Interstellar Extinction, Galaxy Clusters
Frank Tsui, Experimental Condensed Matter and Materials Physics
John Franklin Wilkerson, Experimental Neutrino Physics and Fundamental Symmetries
Yue Wu, Nuclear Magnetic Resonance, Electron Spin Resonance in Solids
Otto Z. Zhou, Materials Science, Nanotechnology

Associate Professors

Akaa Daniel Ayangeakaa, Experimental Nuclear Structure Physics
Andrew W. Mann, Observational Astronomy, Stars and Exoplanets
Amy Nicole Nicholson, Theoretical Nuclear Physics, Computational Lattice Quantum Chromodynamics

Assistant Professors

Gökçe Başar, Theoretical Nuclear and Particle Physics
Julieta Gruszko, Experimental Neutrino Physics

Carl Rodriguez, Computational and Theoretical Astrophysics, Stars, Black Holes, and Gravitational Waves
Wei Zhang, Experimental Condensed Matter Physics, Materials Science

Research Professor

Arthur E. Champagne, Experimental Nuclear Physics and Astrophysics

Research Assistant Professor

Christina Redmon Inscoe, Medical Physics

Teaching Professors

Duane Deardorff, Physics Education Research

Teaching Associate Professors

Stefan Jeglinski, Electronics and Microcontrollers, Machine Learning
Colin Wallace, Physics Education Research
Jennifer Weinberg-Wolf, Physics Education Research

Teaching Assistant Professors

Muxin Zhang, Physics Education Research

Adjunct Professors

Gerald N. Cecil, Observational Astrophysics
Steven Mark Christensen, Gravitation, Quantum Field Theory, Black Holes, Cosmology
Michael R. Flavo, Biological and Medical Physics
Brand Fortner, Astrophysics
Yosuke Kanai, Condensed Matter Physics, Chemical and Material Physics
Alfred Kleinhammes, Condensed Matter Physics, Materials Science
Enrique Platin, Materials Science, Nanotechnology
David Clarke Radford, Nuclear Physics
John Michael Shull, Experimental Astrophysics
Gregory Clayton Sloan, Experimental Astrophysics
Rachel Lofsky Smith, Observational Astronomy
Jie Tang, Materials Physics, Nanomaterials

Adjunct Associate Professors

Brad Barlow, Astrophysics
Alice Churukian, Physics Education Research
David B. Hill, Biophysics
Yueh Z. Lee, Medical Physics
Thomas Osburn, Gravity, Relativity, Theoretical Astrophysics

Professors Emeriti

Charle V. Briscoe
Bruce Carney
Gerald N. Cecil
Wayne Christiansen
Thomas Clegg
Kian S. Dy
John P. Hernandez
Sheila Kannappan
Hugon J. Karwowski
J. Ross Macdonald
Yee Jack Ng
Nalin Parikh
James A. Rose
William J. Thompson
Sean Washburn

ASTR

Advanced Undergraduate and Graduate-level Courses

ASTR 501. Stellar Astrophysics. 3 Credits.
An introduction to the study of stellar structure and evolution. Topics covered include observational techniques, stellar structure and energy transport, nuclear energy sources, evolution off the main-sequence, and supernovae.

Rules & Requirements
Requisites: Prerequisites, ASTR 202 or ASTR 301, MATH 383, and PHYS 331; permission of the instructor for students lacking the prerequisites.
Grading Status: Letter grade.

ASTR 502. Modern Research in Astrophysics. 3 Credits.
A capstone research experience introducing modern data-analysis techniques for large astronomical surveys. Students undertake guided research projects with a different theme each semester. The course focuses on real astrophysical discovery of new objects, events and phenomena.

Rules & Requirements
IDEAs in Action Gen Ed: FC-CREATE, RESEARCH.
Making Connections Gen Ed: EE- Mentored Research.
Requisites: Prerequisite, ASTR 202.
Grading Status: Letter grade.

ASTR 503. Structure and Evolution of Galaxies. 3 Credits.
Overview of the structure and evolution of galaxies, with emphasis on learning and applying modern research methods such as scientific literature review and computational astrostatistics. Includes galaxy morphology and dynamics, star formation, active galactic nuclei, galaxy interactions, large-scale clustering, environment-dependent physical processes, and the evolution of the galaxy population over cosmic time.

Rules & Requirements
Requisites: Prerequisites, ASTR 202 or ASTR 301, MATH 383, and PHYS 331.
Grading Status: Letter grade.

ASTR 504. Cosmology. 3 Credits.
An introduction to modern cosmology: the study of the contents and evolution of the universe. Covers expanding spacetime, the thermal history of the early universe, including nucleosynthesis and the cosmic microwave background, the inflationary model for the origins of cosmic structure, and the growth of that structure through time.

Rules & Requirements
Requisites: Prerequisites, ASTR 202 or ASTR 301, and PHYS 401; pre- or corequisite, PHYS 421.
Grading Status: Letter grade.

ASTR 505. Physics of Interstellar Gas. 3 Credits.
Surveys the physical processes governing the interstellar medium (ISM), which takes up the "refuse" of old stars while providing fuel for young stars forming. Covers the processes regulating the galactic gas budget and the corresponding observational diagnostics. Topics: radiative transfer, line formation mechanisms, continuum radiation, gas dynamics, star formation.

Rules & Requirements
Requisites: Prerequisites, ASTR 202 or ASTR 301, and PHYS 331.
Grading Status: Letter grade.

ASTR 511. Atomic and Radiative Processes in Astrophysics. 3 Credits.
This course covers key topics in electromagnetism, radiative transport, and thermal and statistical mechanics in the context of astrophysics, such as stellar and planetary interiors and atmospheres, stellar evolution (including star formation and death), stellar populations, and the early universe.

Rules & Requirements
Requisites: Prerequisite, ASTR 202; Pre- or corequisite, PHYS 412.
Grading Status: Letter grade.

ASTR 512. Astrophysical Dynamics. 3 Credits.
This course provides a broad overview of astrophysical principles underlying stellar and planetary dynamics; N-body dynamics of star clusters, galaxies, and dark matter; fluid dynamics of astrophysical plasmas; and dynamics of the Universe and spacetime.

Rules & Requirements
Requisites: Prerequisites, ASTR 202 and PHYS 201 or PHYS 401.
Grading Status: Letter grade.

ASTR 519. Observational Astronomy. 4 Credits.
An introduction to modern techniques in observational astronomy with an emphasis on optical and near-infrared wavelengths. Topics covered include practical python for astronomy, telescopes and CCDs, spectroscopy, astrostatistics, and mining large astronomical surveys. Three lecture and three laboratory hours a week.

Rules & Requirements
IDEAs in Action Gen Ed: RESEARCH.
Requisites: Prerequisite, ASTR 102 or 202; Pre- or corequisite, PHYS 331; permission of the instructor for students lacking the prerequisite.
Grading Status: Letter grade.

Graduate-level Courses

ASTR 701. Stellar Interiors, Evolution, and Populations. 3 Credits.
Stellar structure and evolution, including equations of stellar structure, stellar models, star and planet formation, fusion and nucleosynthesis, stellar evolution, stellar remnants, and the comparison of theory to observations.

Rules & Requirements
Grading Status: Letter grade.

ASTR 702. High Energy Astrophysics. 3 Credits.
White dwarfs and neutron stars: physical properties and observational manifestations. Extragalactic radio sources, relativistic jets, and supermassive black holes. Particle acceleration and radiative processes in hot plasmas. Accretion phenomena. X-ray and gamma-ray astrophysics.

Rules & Requirements
Requisites: Prerequisites, PHYS 711 and 721.
Grading Status: Letter grade.

ASTR 703. Structure and Evolution of Galaxies. 3 Credits.
Overview of the structure and evolution of galaxies, with emphasis on learning and applying modern research methods such as scientific literature review and computational astrostatistics. Includes galaxy morphology and dynamics, star formation, active galactic nuclei, galaxy interactions, large-scale clustering, environment-dependent physical processes, and the evolution of the galaxy population over cosmic time.

Rules & Requirements
Grading Status: Letter grade.

ASTR 704. Cosmology. 3 Credits.
General relativity and cosmological world models; thermal history of the early universe, nucleosynthesis, and the cosmic microwave background; growth of structure through cosmic time.

Rules & Requirements
Requisites: Co-requisite, PHYS 701.
Grading Status: Letter grade.

ASTR 705. Physics of Interstellar Gas. 3 Credits.
Surveys the physical processes governing the interstellar medium (ISM), which takes up the "refuse" of old stars while providing fuel for young stars forming. Covers the processes regulating the galactic gas budget and the corresponding observational diagnostics. Topics: radiative transfer, line formation mechanisms, continuum radiation, gas dynamics, star formation.

Rules & Requirements
Requisites: Prerequisites, PHYS 711 and 721.
Grading Status: Letter grade.

ASTR 711. Atomic and Radiative Processes in Astrophysics. 3 Credits.
This course covers key topics in electromagnetism, radiative transport, and thermal and statistical mechanics in the context of astrophysics, such as stellar and planetary interiors and atmospheres, stellar evolution (including star formation and death), stellar populations, and the early universe.

Rules & Requirements
Grading Status: Letter grade.

ASTR 712. Astrophysical Dynamics. 3 Credits.
This course provides a broad overview of astrophysical principles underlying stellar and planetary dynamics; N-body dynamics of star clusters, galaxies, and dark matter; fluid dynamics of astrophysical plasmas; and dynamics of the Universe and spacetime.

Rules & Requirements
Requisites: Prerequisite, PHYS 701.
Grading Status: Letter grade.

ASTR 719. Astronomical Data. 4 Credits.
Required preparation, physics-based cosmology course or permission of the instructor. A course designed to familiarize the student with observational techniques in optical and radio astronomy, including application of photography, spectroscopy, photometry, and radio methods. Three lecture and three laboratory hours a week.

Rules & Requirements
Grading Status: Letter grade.

ASTR 891. Seminar in Astrophysics. 1-21 Credits.
Recent observational and theoretical developments in stellar, galactic, and extragalactic astrophysics.

Rules & Requirements
Grading Status: Letter grade.

PHYS

Advanced Undergraduate and Graduate-level Courses

PHYS 401. Mechanics I. 3 Credits.
Particle kinematics, central forces, planetary motions. Systems of particles, conservation laws, nonlinearity. Statics, motion of rigid bodies. Lagrange's and Hamilton's equations. Euler's equations. Vibrations and waves.

Rules & Requirements
Requisites: Pre- or corequisites, MATH 383 and PHYS 281L and 331; permission of the instructor for students lacking the requisites.
Grading Status: Letter grade.

PHYS 405. Biological Physics. 3 Credits.
How diffusion, entropy, electrostatics, and hydrophobicity generate order and force in biology. Topics include DNA manipulation, intracellular transport, cell division, molecular motors, single molecule biophysics techniques, nerve impulses, neuroscience.

Rules & Requirements
Requisites: Prerequisites, PHYS 116 and 117, or PHYS 118 and 119.
Grading Status: Letter grade.
Same as: BIOL 431, BMME 435.

PHYS 410. Teaching and Learning Physics. 4 Credits.
Learning how to teach physics using current research-based methods. Includes extensive fieldwork in high school environments.

Rules & Requirements
IDEAs in Action Gen Ed: HI-LEARNTA.
Making Connections Gen Ed: EE- Field Work.
Requisites: Prerequisite, PHYS 117 or 119; permission of the instructor for students lacking the prerequisites.
Grading Status: Letter grade.

PHYS 412. Electromagnetism II. 3 Credits.
Electrodynamics: Maxwell's equations and their application to electromagnetic waves, radiation, and relativity.

Rules & Requirements
Requisites: Prerequisites, PHYS 281L, 311 and 332; permission of the instructor for students lacking the prerequisites.
Grading Status: Letter grade.

PHYS 421. Introduction to Quantum Mechanics. 3 Credits.
Origins of quantum theory. Uncertainty principle. Schrödinger equation for simple systems including the hydrogen atom. Spin. Identical particles. Previously offered as PHYS 321.

Rules & Requirements
Requisites: Prerequisites, MATH 383, either MATH 347 or PHYS 331, and one of PHYS 117, or 119; permission of the instructor for students lacking the prerequisites.
Grading Status: Letter grade.

PHYS 422. Physics of the Earth's Interior. 3 Credits.
Origin of the solar system: the nebular hypothesis. Evolution of the earth and its accretionary history. Earthquakes: plate tectonics and the interior of the earth. The earth's magnetic field. Mantle convection.

Rules & Requirements
Requisites: Prerequisites, MATH 383, and either PHYS 201 and 211 or 311 and 401.
Grading Status: Letter grade.
Same as: EMES 422.

PHYS 441. Thermal Physics. 3 Credits.
Equilibrium statistical mechanics; the laws of thermodynamics, internal energy, enthalpy, entropy, thermodynamic potentials, Maxwell's relations.

Rules & Requirements
Requisites: Prerequisites, MATH 233, and PHYS 117 or 119; permission of the instructor for students lacking the prerequisites.
Grading Status: Letter grade.
Same as: BMME 441.

PHYS 447. Quantum Computing. 3 Credits.
Recommended preparation, some knowledge of basic linear algebra. An introduction to quantum computing. Basic math and quantum mechanics necessary to understand the operation of quantum bits. Quantum gates, circuits, and algorithms, including Shor's algorithm for factoring and Grover's search algorithm. Entanglement and error correction. Quantum encryption, annealing, and simulation. Brief discussion of technologies.

Rules & Requirements
Requisites: Prerequisites, MATH 232, and PHYS 116 or 118.
Grading Status: Letter grade.
Same as: COMP 447.

PHYS 451. Electronics I. 4 Credits.
DC and AC circuit analysis and design, construction, test, and measurements. Semiconductors physics and semiconductor devices (diodes and transistors). Signal conditioning and introduction to digital electronics and automated data acquisition and analysis. Previously offered as PHYS 351.

Rules & Requirements
Requisites: Prerequisite, PHYS 115 or 119; Pre- or corequisites, MATH 383 and PHYS 331; permission of the instructor for students lacking the prerequisites.
Grading Status: Letter grade.

PHYS 452. Electronics II. 4 Credits.
Introduction to digital circuits: gates, flip-flops, and counters. Computers and device interconnections, converters and data acquisition. Signal analysis and digital filters. Graphical (LabVIEW) programming and computer interfacing. Individual projects and practical applications. Course previously offered as PHYS 352.

Rules & Requirements
Requisites: Prerequisites, PHYS 451 or BMME 207 and BMME 365; permission of the instructor for students lacking the prerequisites.
Grading Status: Letter grade.

PHYS 461. Introduction to Medical Physics. 3 Credits.
This class will introduce how physics principles and techniques have been applied to medical imaging and radiation therapy. Topics will include ionizing radiation and radiation safety, x-ray and computed tomography, ultrasound, magnetic resonance imaging, positron emission tomography, and radiation therapy. Topics such as the career path to become a medical physicist will also be discussed. The class will have lectures given by the instructor and guest lectures by experts and practitioners in this field.

Rules & Requirements
Requisites: Prerequisites, PHYS 119 or PHYS 115 and MATH 233.
Grading Status: Letter grade.

PHYS 471. Physics of Solid State Electronic Devices. 3 Credits.
Properties of crystal lattices, electrons in energy bands, behavior of majority and minority charge carriers, PN junctions related to the structure and function of semiconductor diodes, transistors, display devices.

Rules & Requirements
Requisites: Prerequisite, PHYS 117 or 119; pre- or corequisite, PHYS 211 or 311.
Grading Status: Letter grade.

PHYS 472. Chemistry and Physics of Electronic Materials Processing. 3 Credits.
A survey of materials processing and characterization used in fabricating microelectronic devices. Crystal growth, thin film deposition and etching, and microlithography. Previously offered as APPL 472. Permission of the instructor.

Rules & Requirements
Requisites: Prerequisite, CHEM 482 or PHYS 117 or 119.
Grading Status: Letter grade.
Same as: CHEM 472.

PHYS 481L. Advanced Laboratory I. 2 Credits.
Selected physical problems to be addressed with the use of materials development, device fabrication and experiment design for evaluation.

Rules & Requirements
IDEAs in Action Gen Ed: RESEARCH, COMMBEYOND.
Requisites: Prerequisites, PHYS 281L, and PHYS 351 or 352; permission of the instructor for students lacking the prerequisites.
Grading Status: Letter grade.

PHYS 491L. Materials Laboratory I. 2 Credits.
Structure determination and measurement of the optical, electrical, and magnetic properties of solids. Previously offered as APPL 491L.

Rules & Requirements
Requisites: Prerequisites, APPL 470 and PHYS 351.
Grading Status: Letter grade.

PHYS 492L. Materials Laboratory II. 2 Credits.
Continuation of PHYS 491L with emphasis on low- and high-temperature behavior, the physical and chemical behavior of lattice imperfections and amorphous materials, and the nature of radiation damage. Previously offered as APPL 492L.

Rules & Requirements
Requisites: Prerequisite, APPL 491L or PHYS 491L.
Grading Status: Letter grade.

PHYS 510. Seminar for Physics and Astronomy Teaching Assistants. 1 Credits.
A seminar on how students learn and understand physics and astronomy and how to teach using current research-based methods.

Rules & Requirements
IDEAs in Action Gen Ed: HI-LEARNTA.
Grading Status: Letter grade.

PHYS 510L. Practicum for Physics and Astronomy Undergraduate Teaching and Learning Assistants. 1 Credits.
This course is designed to accompany, or subsequently follow, the Seminar for New Physics and Astronomy Teaching and Learning Assistants (PHYS 510) and is for undergraduates serving as Undergraduate Teaching Assistants (UTAs) for the Physics and Astronomy Department. UTAs who receive course credit cannot also be paid.

Rules & Requirements
IDEAs in Action Gen Ed: HI-LEARNTA.
Requisites: Pre- or corequisite, PHYS 510.
Repeat Rules: May be repeated for credit. 6 total credits. 6 total completions.
Grading Status: Pass/Fail.

PHYS 515. Optics. 3 Credits.
Broad coverage including ray, wave, Gaussian, and Fourier optics. Interference, diffraction, polarization, and coherence. Optical properties of materials, absorption, scattering. Fiber optics, lasers, semiconductors, imaging, and special topics. Previously offered as PHYS 415.

Rules & Requirements
Requisites: Prerequisite, PHYS 211 or PHYS 412; permission of the instructor for students lacking the prerequisites.
Grading Status: Letter grade.

PHYS 521. Applications of Quantum Mechanics. 3 Credits.
Emphasizes atomic physics but includes topics from nuclear, solid state, and particle physics, such as energy levels, the periodic system, selection rules, and fundamentals of spectroscopy.

Rules & Requirements
Requisites: Prerequisite, PHYS 421.
Grading Status: Letter grade.

PHYS 529. Introduction to Magnetic Resonance. 3 Credits.
This course will provide a broad coverage of important physics principles behind nuclear magnetic resonance (NMR) spectroscopy, especially the applications of quantum mechanics. Theoretical approaches and tools for grasping the design principles of various important NMR spectroscopic techniques will be discussed. It will show, for instance, how to use NMR spectroscopy to determine molecular structures and dynamics, and how to obtain images and functional information using magnetic resonance imaging (MRI).

Rules & Requirements
Requisites: Prerequisite, PHYS 421 or CHEM 486; permission of the instructor for students lacking the prerequisite.
Grading Status: Letter grade.

PHYS 543. Nuclear Physics. 3 Credits.
Structure of nucleons and nuclei, nuclear models, forces and interactions, nuclear reactions.

Rules & Requirements
Requisites: Prerequisite, PHYS 421; permission of the instructor for students lacking the prerequisite.
Grading Status: Letter grade.

PHYS 545. Introductory Elementary Particle Physics. 3 Credits.
Relativistic kinematics, symmetries and conservation laws, elementary particles and bound states, gauge theories, quantum electrodynamics, chromodynamics, electroweak unification, standard model and beyond.

Rules & Requirements
Requisites: Prerequisites, PHYS 412 and 421.
Grading Status: Letter grade.

PHYS 573. Introductory Solid State Physics. 3 Credits.
Crystal symmetry, types of crystalline solids; electron and mechanical waves in crystals, electrical and magnetic properties of solids, semiconductors; low temperature phenomena; imperfections in nearly perfect crystals. Previously offered as APPL 573.

Rules & Requirements
Requisites: Prerequisite, PHYS 421; permission of the instructor for students lacking the prerequisite.
Grading Status: Letter grade.

PHYS 586. Introduction to Biomedical Imaging Science. 3 Credits.
This course offers an introduction to the most common biomedical imaging modalities, including Magnetic Resonance Imaging (MRI), Computed-Tomography (CT), Positron Emission Tomography (PET), Single-Photon Emission Computed Tomography (SPECT), Ultrasound, and Optical Imaging. Lectures include discussions of imaging hardware, and relevant physics, as well as pre-clinical and clinical applications.

Rules & Requirements
Requisites: Prerequisite, PHYS 119.
Grading Status: Letter grade.

PHYS 594. Nonlinear Dynamics. 3 Credits.
Interdisciplinary introduction to nonlinear dynamics and chaos. Fixed points, bifurcations, strange attractors, with applications to physics, biology, chemistry, finance.

Rules & Requirements
Requisites: Prerequisite, MATH 383; permission of the instructor for students lacking the prerequisite.
Grading Status: Letter grade.
Same as: MATH 594.

PHYS 631. Mathematical Methods of Theoretical Physics. 3 Credits.
Linear vector spaces and matrices, curvilinear coordinates, functions of complex variables, ordinary and partial differential equations, Fourier series, integral transforms, special functions, differential forms.

Rules & Requirements
Requisites: Prerequisites, PHYS 281L and 332.
Grading Status: Letter grade.

PHYS 632. Advanced Research Analytics. 3 Credits.
Required preparation, ability to program in a high-level computer language. Permission of the instructor for students lacking the required preparation. Methods required for the analysis, interpretation, and evaluation of physics measurements and theory. Error analysis, statistical tests, model fitting, parameter estimation, Monte Carlo methods, Bayesian inference, noise mitigation, experimental design, big data, selected numerical techniques including differential equations and Fourier techniques.

Rules & Requirements
Grading Status: Letter grade.

PHYS 633. Scientific Programming. 3 Credits.
Required preparation, elementary Fortran, C, or Pascal programming. Structured programming in Fortran or Pascal; use of secondary storage and program packages; numerical methods for advanced problems, error propagation and computational efficiency; symbolic mathematics by computer.

Rules & Requirements
Requisites: Prerequisite, MATH 528 or 529, or PHYS 631 or 632.
Grading Status: Letter grade.

PHYS 660. Fluid Dynamics. 3 Credits.
The physical properties of fluids, kinematics, governing equations, viscous incompressible flow, vorticity dynamics, boundary layers, irrotational incompressible flow. Course previously offered as GEOL 560/ MASC 560.

Rules & Requirements
Requisites: Prerequisite, PHYS 401; permission of the instructor for students lacking the prerequisite.
Grading Status: Letter grade.
Same as: EMES 560, ENVR 452.

PHYS 671L. Independent Laboratory I. 3 Credits.
Six laboratory hours a week.

Rules & Requirements
Requisites: Prerequisites, PHYS 401 and 412; permission of the instructor for students lacking the prerequisites.
Grading Status: Letter grade.

PHYS 672L. Independent Laboratory II. 3 Credits.
Six laboratory hours a week.

Rules & Requirements
Requisites: Prerequisites, PHYS 401 and 412; permission of the instructor for students lacking the prerequisites.
Grading Status: Letter grade.

PHYS 691H. Senior Honor Thesis Research I. 3 Credits.
Permission of the instructor. Readings in physics and directed research for a senior honor thesis project. Required of all candidates for graduation with honors in physics.

Rules & Requirements

IDEAs in Action Gen Ed: RESEARCH.
Making Connections Gen Ed: EE- Mentored Research.
Grading Status: Letter grade.

PHYS 692H. Senior Honor Thesis Research II. 3 Credits.
Readings in physics and directed research for a senior honor thesis project. Required of all candidates for graduation with honors in physics.

Rules & Requirements

IDEAs in Action Gen Ed: RESEARCH.
Making Connections Gen Ed: EE- Mentored Research.
Requisites: Prerequisite, PHYS 691H.
Grading Status: Letter grade.

Graduate-level Courses

PHYS 701. Classical Dynamics. 3 Credits.
Variational principles, Lagrangian and Hamiltonian mechanics. Symmetries and conservation laws. Two-body problems, perturbations, and small oscillations, rigid-body motion. Relation of classical to quantum mechanics.

Rules & Requirements
Requisites: Prerequisite, advanced undergraduate mechanics.
Grading Status: Letter grade.

PHYS 711. Electromagnetic Theory I. 3 Credits.
Electrostatics, magnetostatics, time-varying fields, Maxwell's equations.

Rules & Requirements
Requisites: Prerequisites, PHYS 631 and 632.
Grading Status: Letter grade.

PHYS 712. Electromagnetic Theory. 3 Credits.
Maxwell's equations, time-varying fields, and conservation laws. Plane EM waves, polarization, propagation, dispersive media. Wave guides and resonant cavities. Radiation from slow-moving charges. Special theory of relativity. Radiation from relativistic charges. Interaction between radiation and matter.

Rules & Requirements
Grading Status: Letter grade.

PHYS 715. Visualization in the Sciences. 3 Credits.
Computational visualization applied in the natural sciences. For both computer science and natural science students. Available techniques and their characteristics, based on human perception, using software visualization toolkits. Project course.

Rules & Requirements
Grading Status: Letter grade.
Same as: COMP 715, MTSC 715.

PHYS 721. Quantum Mechanics. 3 Credits.
Review of nonrelativistic quantum mechanics. Spin, angular momentum, perturbation theory, scattering, identical particles, Hartree-Fock method, Dirac equation, radiation theory.

Rules & Requirements
Requisites: Prerequisite, PHYS 421.
Grading Status: Letter grade.

PHYS 722. Quantum Mechanics. 3 Credits.
Review of nonrelativistic quantum mechanics. Spin, angular momentum, perturbation theory, scattering, identical particles, Hartree-Fock method, Dirac equation, radiation theory.

Rules & Requirements
Requisites: Prerequisite, PHYS 421.
Grading Status: Letter grade.

PHYS 741. Statistical Mechanics. 3 Credits.
Classical and quantal statistical mechanics, ensembles, partition functions, ideal Fermi and Bose gases.

Rules & Requirements
Requisites: Prerequisites, PHYS 701 and 721.
Grading Status: Letter grade.

PHYS 771L. Advanced Spectroscopic Techniques. 3 Credits.
Advanced spectroscopic techniques, including Rutherford backscattering-channeling, perturbed angular correlation, Raman scattering, electron paramagnetic resonance, nuclear magnetic resonance, optical absorption, and Hall effect. Two hours of lecture and three hours of laboratory a week.

Rules & Requirements
Requisites: Prerequisite, PHYS 401 or 412; permission of the instructor for students lacking the prerequisite.
Grading Status: Letter grade.

PHYS 772L. Advanced Spectroscopic Techniques. 3 Credits.
Advanced spectroscopic techniques, including Rutherford backscattering-channeling, perturbed angular correlation, Raman scattering, electron paramagnetic resonance, nuclear magnetic resonance, optical absorption and Hall effect. One hour of lecture and five hours of laboratory a week.

Rules & Requirements
Requisites: Prerequisite, PHYS 401 or 412; permission of the instructor for students lacking the prerequisite.
Grading Status: Letter grade.

PHYS 780. Advanced Materials Science. 3 Credits.
This course covers the physical fundamentals of material science with an in-depth discussion of structure formation in soft and hard materials and how structure determines material mechanical, electrical, thermal, and optical properties. Topics include amorphous and crystal structures, defects, dislocation theory, thermodynamics and phase diagrams, diffusion, interfaces and microstructures, solidification, and theory of phase transformation. Special emphasis will be on the structure-property relationships of (bio)polymers, (nano)composites, and their structure property relationships.

Rules & Requirements
Grading Status: Letter grade.
Same as: MTSC 780, BMME 780, CHEM 780.

PHYS 821. Advanced Quantum Mechanics. 3 Credits.
Advanced angular momentum, atomic and molecular theory, many-body theory, quantum field theory.

Rules & Requirements
Requisites: Prerequisite, PHYS 722.
Grading Status: Letter grade.

PHYS 822. Field Theory. 3 Credits.
Quantum field theory, path integrals, gauge invariance, renormalization group, Higgs mechanism, electroweak theory, quantum chromodynamics, Standard Model, unified field theories.

Rules & Requirements
Requisites: Prerequisite, PHYS 722.
Grading Status: Letter grade.

PHYS 823. Field Theory. 3 Credits.
Quantum field theory, path integrals, gauge invariance, renormalization group, Higgs mechanism, electroweak theory, quantum chromodynamics, Standard Model, unified field theories.

Rules & Requirements
Requisites: Prerequisite, PHYS 722.
Grading Status: Letter grade.

PHYS 824. Group Theory and its Applications. 3 Credits.
Required preparation, knowledge of matrices, mechanics, and quantum mechanics. Discrete and continuous groups. Representation theory. Application to atomic, molecular, solid state, nuclear, and particle physics.

Rules & Requirements
Grading Status: Letter grade.

PHYS 829. Principles of Magnetic Resonance. 3 Credits.
Rules & Requirements
Requisites: Prerequisite, CHEM 781 or PHYS 721; permission of the instructor for students lacking the prerequisite.
Grading Status: Letter grade.

PHYS 831. Differential Geometry in Modern Physics. 3 Credits.
Applications to electrodynamics, general relativity, and nonabelian gauge theories of methods of differential geometry, including tensors, spinors, differential forms, connections and curvature, covariant exterior derivatives, and Lie derivatives.

Rules & Requirements
Requisites: Prerequisites, PHYS 701, 711, and 712.
Grading Status: Letter grade.

PHYS 832. General Theory of Relativity. 3 Credits.
Differential geometry of space-time. Tensor fields and forms. Curvature, geodesics. Einstein's gravitational field equations. Tests of Einstein's theory. Applications to astrophysics and cosmology.

Rules & Requirements
Requisites: Prerequisite, PHYS 831; permission of the instructor for students lacking the prerequisite.
Grading Status: Letter grade.

PHYS 861. Nuclear Physics. 3 Credits.
Nuclear reactions, scattering, nuclear structure, nuclear astrophysics.

Rules & Requirements
Requisites: Prerequisites, PHYS 543 and 721.
Grading Status: Letter grade.

PHYS 862. Nuclear Physics. 3 Credits.
Overview of Standard Model of particle physics. Fundamental symmetries and weak interactions. Neutrino physics. Particle-astrophysics and cosmology.

Rules & Requirements
Requisites: Prerequisites, PHYS 543 and 721.
Grading Status: Letter grade.

PHYS 871. Solid State Physics. 3 Credits.
Topics considered include those of PHYS 573, but at a more advanced level, and in addition a detailed discussion of the interaction of waves (electromagnetic, elastic, and electron waves) with periodic structures, e.g., X-ray diffraction, phonons, band theory of metals and semiconductors.

Rules & Requirements
Requisites: Prerequisite, PHYS 421; equivalent experience for students lacking the prerequisite.
Grading Status: Letter grade.
Same as: MTSC 871.

PHYS 872. Solid State Physics II. 3 Credits.
Topics considered include quantum and thermal fluctuations, and thermodynamics of phase transitions in a broad variety of condensed matter systems, their kinetic theory and hydrodynamics, novel materials (two-dimensional electron gas, graphene, topological insulators and superconductors, Dirac/Weyl/nodal line semimetals), condensed matter applications of modern field-theoretical methods (path integral, renormalization group, holography).

Rules & Requirements
Requisites: Prerequisite, PHYS 871.
Grading Status: Letter grade.
Same as: MTSC 872.

PHYS 873. Theory of the Solid State. 3 Credits.
Calculation of one-electron energy band structure. Electron-hole correlation effect and excitons. Theory of spin waves. Many-body techniques in solid state problems including theory of superconductivity.

Rules & Requirements
Requisites: Prerequisite, PHYS 722.
Grading Status: Letter grade.

PHYS 883. Current Advances in Physics. 3 Credits.
Permission of the instructor. In recent years, elementary particle physics, amorphous solids, neutrinos, and electron microscopy have been among the topics discussed.

Rules & Requirements
Grading Status: Letter grade.

PHYS 885. Introductory Graduate Seminar in Physics and Astronomy. 1 Credits.
Introduction to skills needed for success in graduate courses and research, including practice using general-purpose mathematical/computational tools, assessment of the research landscape and research project design, preparing a proposal, and participating in peer review. Professional development topics such as ethics and etiquette, time management, and career planning are also covered.

Rules & Requirements
Grading Status: Letter grade.

PHYS 893. Seminar in Solid State Physics. 1-21 Credits.
Research topics in condensed-matter physics, with emphasis on current experimental and theoretical studies.

Rules & Requirements
Grading Status: Letter grade.

PHYS 895. Seminar in Nuclear Physics. 1-21 Credits.
Current research topics in low-energy nuclear physics, especially as related to the interests of the Triangle Universities Nuclear Laboratory.

Rules & Requirements
Grading Status: Letter grade.

PHYS 896. Seminar in Particle Physics. 1-21 Credits.
Symmetries, gauge theories, asymptotic freedom, unified theories of weak and electromagnetic interactions, and recent developments in field theory.

Rules & Requirements
Grading Status: Letter grade.

PHYS 897. Seminar in Theoretical Physics. 1-21 Credits.
Topics from current theoretical research including, but not restricted to, field theory, particle physics, gravitation, and relativity.

Rules & Requirements
Grading Status: Letter grade.

PHYS 899. Seminar in Professional Practice. 1-21 Credits.
Required preparation, Ph.D. written exam passed. The role and responsibilities of a physicist in the industrial or corporate environment and as a consultant.

Rules & Requirements
Grading Status: Letter grade.

PHYS 901. Research. 1-21 Credits.
10 or more laboratory or computation hours a week.

Rules & Requirements
Grading Status: Letter grade.

PHYS 992. Master's (Non-Thesis). 3 Credits.
Rules & Requirements
Repeat Rules: May be repeated for credit.

PHYS 993. Master's Research and Thesis. 3 Credits.
Rules & Requirements
Repeat Rules: May be repeated for credit.

PHYS 994. Doctoral Research and Dissertation. 3 Credits.
Fall or spring. Staff.

Rules & Requirements
Repeat Rules: May be repeated for credit.

**The PHYS 821 and PHYS 896 sequence alternates with PHYS 822 and PHYS 823.*

Contact Information

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Chair
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