PHYSICS (PHY)

Master of Science, Doctor of Philosophy

Overview

Opportunities for study are those usually associated with large research universities, while the atmosphere of a small liberal arts university with an ideal faculty/student ratio is maintained.

For admission to the program, students should have knowledge of senior level undergraduate mechanics, electricity and magnetism, thermodynamics, and quantum physics. The course of study for each first-year student is planned in conference with the graduate advisor after an evaluation of academic background and experience. Deficiencies may be removed during the first year of study by taking remedial courses.

The research interests of the graduate faculty are in experimental and computational biophysics, nanotechnology, optics, experimental and theoretical condensed matter physics, quantum computing, quantum materials and quantum optics, and gravitation. All research laboratories are well-equipped with state-of-the-art instrumentation, such as subpicosecond pulsed lasers; EPR; time-resolved, UV-vis spectrophotometers; optical tweezers; atomic force microscopes; single molecule manipulators; high-sensitivity optical and confocal microscopes; numerous, standard biochemical research apparatuses; and others. The Center of Nanotechnology and Molecular Materials (*www.wfu.edu/nanotech*), which houses state-of-the-art electron microscopes, sample analysis and preparation instruments and a clean room, is part of the physics department. Computational and theoretical research is supported by the DEAC Linux Cluster (deac.wfu.edu (https://is.wfu.edu/services/high-performance-computing/)) with several thousand computational processing cores.

For more details on the PhD program, visit *www.wfu.edu/physics* or write to the program director.

Programs

- Physics, MS (https://bulletin.wfu.edu/graduate/programs/degree-programs/physics/physics-ms/)
- Physics, PhD (https://bulletin.wfu.edu/graduate/programs/degree-programs/physics/physics-phd/)
- MD/PhD (https://bulletin.wfu.edu/graduate/programs/dual-degrees/md-phd/)
- PhD/MBA (https://bulletin.wfu.edu/graduate/programs/dual-degrees/phd-mba/)
- Structural and Computational Biophysics (SCB), Certificate (https://bulletin.wfu.edu/graduate/programs/certificates/structural-computational-biophysics-scb-certificate/)

Courses

PHY 601. Physics Seminar. (0.5 h)
Discussion of contemporary research, usually with visiting scientists. S/U only.

PHY 607. Biophysics. (3 h)
Introduction to the structure, dynamic behavior, and function of DNA and proteins, and a survey of membrane biophysics. The physical principles of structure determination by X-ray, NMR, and optical methods are emphasized.

PHY 610. Extragalactic Astronomy and Cosmology. (3 h)
Topics covered include galactic structure, models for galaxies and galaxy formation, the large-scale structure of the universe, the Big Bang model of the universe, physical processes such as nucleosynthesis in the early universe, and observational cosmology.

PHY 620. Physics of Macromolecules. (3 h)
The physics of large biologically important molecules, especially proteins and nucleic acids. Topics covered include the physical basis of biomolecular structure, the energetics and statistical mechanics of biomolecular dynamics, and the electrostatics and solvation of biomolecules. Designed for students with biochemistry, chemistry, or physics backgrounds.

PHY 623. Computational Biophysics Laboratory. (1 h)
Application of techniques in molecular modeling, including energy minimization, molecular dynamics simulation, and conformational analysis. C-PHY 620 or POI.

PHY 625. Biophysical Methods Lab. (1.5 h)
Experiments using various biophysical techniques such as electron paramagnetic resonance, atomic force microscopy, stopped-flow absorption spectroscopy, X-ray diffraction, and gel electrophoresis. C-PHY 607.

PHY 635. Computational Physics. (3 h)
An introduction to finding numerical solutions to scientific problems. Topics include understanding computational errors, differentiation, integration interpolation, root finding, random numbers, linear systems, Fourier methods, and the solution of ODEs and PDEs. There is no computer programming prerequisite. Credit will not be given for both PHY 635 and CSC 655/MST 655.

PHY 637. Analytical Mechanics. (1.5 h)
The Lagrangian and Hamiltonian formulations of mechanics with applications. Taught in the first half of the fall semester.

PHY 639. Electricity and Magnetism. (1.5 h)
Electrostatics, magnetostatics, dielectric and magnetic materials, Maxwell's equations and applications to radiation, relativistic formulation. The first half course is taught in the second half of the fall semester, following PHY 637. The other course is taught in the spring semester. These should be taken in sequence.

PHY 640. Electricity and Magnetism. (3 h)
Electrostatics, magnetostatics, dielectric and magnetic materials, Maxwell's equations and applications to radiation, relativistic formulation. PHY 640 is taught in the spring semester after PHY 639. These should be taken in sequence. P-PHY 639.

PHY 641. Thermodynamics and Statistical Mechanics. (3 h)
Introduction to classical and statistical thermodynamics and distribution functions.

PHY 643. Quantum Physics. (3 h)
Basic quantum theory and applications including the time-independent Schrodinger equation, formalism and Dirac notation, the hydrogen atom, spin, identical particles, and approximation models.

PHY 644. Quantum Physics. (3 h)
Basic quantum theory and applications including the time-independent Schrodinger equation, formalism and Dirac notation, the hydrogen atom, spin, identical particles, and approximation methods.

PHY 645. Introduction to Quantum Computing. (3 h)
Introduction to the physics of quantum information sciences and quantum computing.

PHY 652. Physical Optics and Optical Design. (4 h)
Interaction of light with materials; diffraction and coherent optics; ray trace methods of optical design. C-PHY 652L.

PHY 652L. Physical Optics Lab. (0 h)

PHY 654. Introduction to Solid State Physics. (3 h)
Survey of the structure, composition, physical properties, and technological applications of condensed matter. P-PHY 643.

PHY 655. Quantum Materials. (3 h)
This course explores materials systems that express exotic properties derived from some aspect of dimensionality or topology. Thermal, electrical, optical and magnetic properties of these quantum materials will be addressed with emphasis on applications in quantum information sciences. From superconducting SSH polymers, to topological insulators, simple models are used throughout the course to develop insight into the physics of low-dimensional structures.

PHY 656. Electronic Imaging Sciences. (1.5 h)
This course introduces the theory and application of the electron imaging systems: transmission electron microscopy (TEM) and scanning electron microscopy (SEM). It focuses on basic materials science though some biological materials will be covered. It is taught as a series of lectures followed by laboratories.

PHY 657. Scanning Probes. (1.5 h)
This course examines the theory and application of scanning tunneling microscopy and atomic force microscopy (STM/AFM). It introduces how each type of imaging works, how to model spectroscopic data, and how to use each microscope. Students will image using the STM and AFM as well as take and reduce spectroscopy data using models built in Maple or Mathematica.

PHY 658. Kinetics of Materials. (1.5 h)
This course offers a study of driving forces for atomic and ionic motion within solids leading to a range of materials properties from work hardening to phase transformations and formation. Atomic-level models for diffusion will be introduced as well as techniques and examples of the solution to the diffusion equation. It complements the traditional thermodynamics course.

PHY 661. Biophysics Seminar. (1 h)
Seminal and current publications in biophysics are studied. Each week a member of the class makes an oral presentation on a chosen publication and leads the ensuing discussion. Students may also be required to make a second oral presentation relevant to their own research. Does not fulfill course requirements for Master's or PhD degrees. May be repeated for credit. S/U only.

PHY 663. Condensed Matter Seminar. (1 h)
Seminal and current publications in condensed matter physics are studied. Each week a member of the class makes an oral presentation on a chosen publication and leads the ensuing discussion. Does not fulfill course requirements for Master's or PhD degrees. May be repeated for credit. S/U only.

PHY 685. Bioinformatics. (3 h)
Introduction to computational approaches essential to modern biological inquiry. Approaches may include large biological dataset analyses, sequence similarity and motif searches, and analysis of high-throughput genomic technologies. Emphasizes interdisciplinary interaction and communication. Also listed as CSC 685 and BIO 685.

PHY 691. Special Topics in Physics. (1-4 h)
Courses in selected topics in physics. May be repeated if course contenct differs.

PHY 692. Special Topics in Physics. (1-4 h)
Courses in selected topics in physics. May be repeated if course content differs.

PHY 711. Classical Mechanics and Mathematical Methods. (3 h)
A study of variational principles and Lagrange's equations, the rigid body equations of motion, the Hamilton equations of motion and canonical transformations, Hamilton-Jacobi theory, and applications to continuous systems and fields.

PHY 712. Electromagnetism. (3 h)
A study of electric and magnetic fields in vacuum and within media and their sources. Analytical and numerical methods for solving Maxwell's equations are also an important part of the course.

PHY 715. Nonlinear Optics and Quantum Electronics. (3 h)
Nonlinear phenomena in laser spectroscopy, the quantum nature of optical processes in matter, and topics in laser physics. Lab-three hours.

PHY 731. Elementary Particle Physics. (3 h)
Fundamentals of contemporary elementary particle physics.

PHY 741. Quantum Mechanics. (3 h)
Study of the foundations of quantum theory, Hilbert space, operators, Schrodinger's equation and its solutions, symmetries, spin, multiple particles, approximation methods, scattering, the Dirac equation, and quantization of the electromagnetic field and its interaction with atoms.

PHY 742. Quantum Mechanics. (3 h)
Study of the foundations of quantum theory, Hilbert space, operators, Schrodinger's equation and its solutions, symmetries, spin, multiple particles, approximation methods, scattering, the Dirac equation, and quantization of the electromagnetic field and its interaction with atoms.

PHY 744. Introduction to Quantum Field Theory. (3 h)
Introduction to relativistic quantum field theory, including canonical quantization, path integral techniques, perturbation theory, and renormalization.

PHY 745. Group Theory. (3 h)
Group theory and its applications to the quantum mechanics of atoms, molecules, and solids.

PHY 746. Quantum Information Theory. (3 h)

PHY 752. Solid State Physics. (3 h)
Introductory course including the structure of perfect crystalline solids, their thermal, electronic, and magnetic properties. Crystal symmetries, the free electron and band theory of metals, optical and transport properties, and semiconductors. Consequences of electronic interactions.

PHY 754. Surface Science. (3 h)
Experimental and theoretical methods for the study of surfaces and interfaces. Lab-1.5 hours.

PHY 765. Gravitational and Particle Theory Seminar. (1 h)
Topics in general relativity, particle physics, and astrophysics are studied. Each week a faculty member or member of the class makes an oral presentation on a chosen topic and leads the ensuing discussion. Does not fulfill minimum course requirements for Master's and PhD degrees. May be repeated for credit. S/U only.

PHY 770. Statistical Mechanics. (3 h)
Introduction to probability theory and to the physics of systems containing large numbers of particles from the classical as well as the quantum point of view.

PHY 771. Radiological Physics. (3 h)
The nature and fundamental concepts of ionizing radiation including: ionizing radiation, radiation quantities, attenuation and stopping power, charged particle and radiation equilibria radioactive decay, photon interactions, charged and uncharged particle interactions, x-ray production and quality, dosimetry concepts, ionization cavity theory, and calibration of ionizing radiation beams. Also listed as BMES 771 and MPHY 771.

PHY 773. Radiation Therapy Physics. (3 h)
The physics of radiation treatment including: radiation producing equipment, character of photon and electron radiation beams, radiation dose functions, computerized radiation treatment planning, brachytheraphy, special radiation treatment procedures, quality assurance, and radiation shielding for high energy facilities. Also listed as BMES 773 and MPHY 773.

PHY 774. Ionizing Medical Imaging. (2 h)
This course covers the physical principles, mathematical algorithms and devices used in diagnostic medical imaging, including the following imaging modalities: x-ray digital imaging, digital image receptors, computerized tomography and reconstruction algorithms, ultrasound imaging, magnetic resonance imaging and nuclear medicine imaging. Also listed as BMES 774 and MPHY 774.

PHY 776. Medical Health Physics. (3 h)
Physical and biological aspects for the use of ionizing radiation in medical environments, biological consequences of human radiation exposure, principles of ionizing radiation protection, operational dosimetry, radiation exposure recommendations and regulations, physical principles of radiation shielding design, personnel monitoring, medical health physics instrumentation, and waste disposal. Also listed as BMES 776 and MPHY 776.

PHY 779. Non-Ionizing Medical Imaging. (2 h)
This course covers the physical principles, mathematical algorithms and devices used in diagnostic medical imaging which uses non-ionizing radiation, including the following imaging modalities: x-ray physics, x-ray digital imaging, digital image receptors, computerized tomography and reconstruction algorithms, and nuclear medicine imaging. Also listed as MPHY 779.

PHY 780. Theory of General Relativity. (3 h)
Study of the covariant formulation of physical laws in mechanics and electromagnetism.

PHY 785. Topics in Theoretical Physics. (1-3 h)
Selected topics of current interest in theoretical physics not included in other courses. May be repeated for credit.

PHY 787. Advanced Topics in Physics. (1-3 h)
Lectures on advanced topics in physics that depend on the subspecialty of the instructor. Topics range from medical physics to special topics in biophysics, condensed matter physics, or quantum optics.

PHY 789. Survival Skills for Scientists. (1 h)
Students will learn skills that are essential to a successful career in the sciences. The following topics will be covered: Mentoring; How to Read, Write, and Review a Research Paper; Grant & Fellowship Basics; Choosing a Career Path & Creating a Winning Job Application; and Networking & Giving Effective Talks.

PHY 791. Thesis Research I. (1-9 h)
May be repeated for credit. Satisfactory/Unsatisfactory.

PHY 792. Thesis Research II. (1-9 h)
May be repeated for credit. Satisfactory/Unsatisfactory.

PHY 795. Physics for Education Research. (3 h)
This course will fulfill the requirement for a graduate course in Physics for students in the Masters in Education program seeking certification to teach Physics. This course involves research with a Physics advisor, with a poster or paper report as a final product.

PHY 891. Dissertation Research I. (1-9 h)
May be repeated for credit. Satisfactory/Unsatisfactory.

PHY 892. Dissertation Research II. (1-9 h)
May be repeated for credit. Satisfactory/Unsatisfactory.

Faculty

Program Director and Professor Freddie Salsbury
Professor and Department Chair Martin Guthold
Professor and Richard T Williams Faculty Chair in Physics Keith Bonin
Baker Family Professor of Physics Oana Jurchescu
Professor and Harbert Family Distinguished Chair Daniel B. Kim-Shapiro
Professor and Wright Family Endowed Chair in Physics Timo Thonhauser

Professors David L. Carroll, Jed Macosko
Associate Professors Eric D. Carlson, Samuel S. Cho, Gregory B. Cook
Assistant Professors Alejandro Cardenas-Avendano, Emilie Huffman, Ajay Ram Srimath Kandada, Stephen M. Winter, Caitlin Witt
Adjunct Professors J. Daniel Bourland, Michael Munley, Peter Santago
Adjunct Associate Professor Adam R. Hall
Affiliate Associate Professors Erin Henslee, Lauren Lowman