DEPARTMENT OF PHYSICS AND ASTRONOMY

http://physics.tamu.edu

Head: G. V. Rogachev

Graduate Advisors: J. Ross (Physics and Applied Physics); L. Macri (Astronomy)

The physics and astronomy curriculum provides classroom and research experience that prepares a graduate student for a career of either research and teaching at a university, or research and development at an industrial or government laboratory. The courses are well suited to graduate students in chemistry, mathematics, geosciences or engineering, as well as those seeking a graduate degree in physics or astronomy.

The faculty members of the department carry out theoretical and experimental research in the following areas: astronomy, atomic and molecular, computational physics, cosmology, high-energy, low-temperature/condensed matter, materials science, nuclear physics, and quantum optics. Laboratories supporting the experimental programs are well-equipped with modern research apparatus. Special support facilities include an astronomical instrumentation laboratory, access to high-performance computing, a variable-energy cyclotron, and many shared campus facilities.

Faculty

Abanov, Artem G, Associate Professor
Physics & Astronomy
PHD, Texas A&M University, 1998

Agnolet, Glenn, Professor
Physics & Astronomy
PHD, Cornell University, 1983

Akimov, Alexey, Assistant Professor
Physics & Astronomy
PHD, Moscow Institute of Technology, 2003

Allen, Roland E, Professor
Physics & Astronomy
PHD, University of Texas at Austin, 1969

Aronson, Meigan C, Professor
Physics & Astronomy
PHD, University of Illinois - Urbana-Champaign, 1988

Bassichis, William H, Professor
Physics & Astronomy
PHD, Case Western Reserve University, 1963

Becker, Katrin, Professor
Physics & Astronomy
PHD, University of Bonn, 1994

Becker, Melanie, Professor
Physics & Astronomy
PHD, University of Bonn, Germany, 1994

Belyanin, Alexey A, Professor
Physics & Astronomy
PHD, Institute of Applied Physics Russian Academy of Sciences, 1995

Chin, Siu A, Professor
Physics & Astronomy
PHD, Massachusetts Institute of Technology, 1975

Christian, Gregory A, Assistant Professor
Physics & Astronomy
PHD, Michigan State University, 2011

Depoy, Darren L, Professor
Physics & Astronomy
PHD, University of Hawaii at Manoa, 1987

Dierker, Steven B, Professor
Physics & Astronomy
PHD, University of Illinois-Urbana-Champaign, 1983

Dutta, Bhaskar, Professor
Physics & Astronomy
PHD, Oklahoma State University, 1995

Ershkchina, Tatiana L, Instructional Associate Professor
Physics & Astronomy
DOE, Institute of Applied Physics, Russian Academy of Sciences, 1999

Eusebi, Ricardo, Associate Professor
Physics & Astronomy
PHD, University of Rochester, 2006

Finkelstein, Alexander, Professor
Physics & Astronomy
PHD, University of Rochester, 1972

Ford, Albert L, Professor
Physics & Astronomy
PHD, University of Texas at Austin, 1972

Fries, Rainer J, Associate Professor
Physics & Astronomy
PHD, University of Regensburg, 2001

Fry, Edward S, Distinguished Professor
Physics & Astronomy
PHD, University of Michigan, 1969

Gagliardi, Carl A, Professor
Physics & Astronomy
PHD, Princeton University, 1982

Hardy, John C, Distinguished Professor
Physics & Astronomy
PHD, McGill University, 1965

Herschbach, Dudley R, Distinguished Professor
Physics & Astronomy
PHD, Harvard University, 1958

Holt, Jeremy W, Assistant Professor
Physics & Astronomy
PHD, Stony Brook University, 2008
Kamon, Teruki, Professor
Physics & Astronomy
PHD, University of Tsukuba, 1986

Katzgraber, Helmut G, Professor
Physics & Astronomy
PHD, University of California-Santa Cruz, 2001

Ke, Che-Ming, Professor
Physics & Astronomy
PHD, State University of New York at Stony Brook, 1973

Kocharoskaya, Olga A, Distinguished Professor
Physics & Astronomy
PHD, Institute of Applied Physics, Russian Academy of Sciences, 1986

Kocharovsky, Vitaly V, Professor
Physics & Astronomy
PHD, Institute of Applied Physics, Russian Academy of Sciences, 1986

Krisiunas, Kevin L, Instructional Assistant Professor
Physics & Astronomy
PHD, University of Washington, 2000

Lee, David M, Distinguished Professor
Physics & Astronomy
PHD, Yale University, 1959

Lyuksyutov, Igor F, Professor
Physics & Astronomy

Macri, Lucas M, Professor
Physics & Astronomy
PHD, Harvard University, 2001

Mahapatra, Rupak K, Professor
Physics & Astronomy
PHD, University of Minnesota, 2000

Marshall, Jennifer L, Assistant Professor
Physics & Astronomy
PHD, Ohio State University, 2006

Mason, John D, Lecturer
Physics & Astronomy
PHD, Texas A&M University, 2016

McIntyre, Peter M, Professor
Physics & Astronomy
PHD, University of Chicago, 1973

Melconian, Daniel G, Associate Professor
Physics & Astronomy
PHD, Simon Fraser University, 2006

Mioduszewski, Saskia, Professor
Physics & Astronomy
PHD, University of Tennessee, 1999

Mirabolfathi, Nader, Research Associate Professor
Physics & Astronomy
PHD, University of Paris XI, 2002

Nanopoulos, Dimitri V, Distinguished Professor
Physics & Astronomy
PHD, University of Sussex, 1973

Naugle, Donald G, Professor
Physics & Astronomy
PHD, Texas A&M University, 1965

Papovich, Casey J, Professor
Physics & Astronomy
PHD, Johns Hopkins University, 2002

Pokrovsky, Valery, Distinguished Professor
Physics & Astronomy
PHD, Tomsk State University, 1957

Pope, Christopher N, Distinguished Professor
Physics & Astronomy
PHD, University of Cambridge, 1980

Rapp, Ralf F, Professor
Physics & Astronomy
PHD, Rheinische Friedrich-Wilhelma University, Bonn, 1996

Rogachev, Grigory V, Professor
Physics & Astronomy
PHD, National Research Centre, 1999

Ross Jr, Joseph H, Professor
Physics & Astronomy
PHD, University of Illinois at Urbana-Champaign, 1986

Safonov, Alexei N, Professor
Physics & Astronomy
PHD, University of Florida, 2001

Saslow, Wayne M, Professor
Physics & Astronomy
PHD, University of California - Irvine, 1968

Schuessler, Hans A, Professor
Physics & Astronomy
DOC, Universitat Heidelberg, 1964

Scully, Marlan O, Distinguished Professor
Physics & Astronomy
PHD, Yale University, 1966

Sezgin, Ergin, Professor
Physics & Astronomy
PHD, State University of New York at Stony Brook, 1980

Sokolov, Alexei V, Professor
Physics & Astronomy
PHD, Stanford University, 2001

Strigari, Louis E, Assistant Professor
Physics & Astronomy
PHD, Ohio State University, 2005

Suntzeff, Nicholas B, Distinguished Professor
Physics & Astronomy
PHD, University of California - Santa Cruz, 1980
Svidzinsky, Anatoly A, Research Associate Professor
Physics & Astronomy
PHD, Stanford University, 2001

Teizer, Winfried, Professor
Physics & Astronomy
PHD, University of Massachusetts - Amherst, 1998

Toback, David, Professor
Physics & Astronomy
PHD, University of Chicago, 1997

Tran, Kim-Vy H, Professor
Physics & Astronomy
PHD, University of California, Santa Cruz, 2002

Tribble, Robert E, Distinguished Professor
Physics & Astronomy
PHD, Princeton University, 1973

Walsh, Jonelle L, Assistant Professor
Physics & Astronomy
PHD, University of California, Irvine, 2011

Wang, Dawei, Research Associate Professor
Physics & Astronomy
PHD, Chinese University of Hong Kong, 2012

Wang, Lifan, Professor
Physics & Astronomy
PHD, University of Science and Technology of China, 1993

Webb, Robert C, Professor
Physics & Astronomy
PHD, Princeton University, 1972

Weimer, Michael B, Professor
Physics & Astronomy
PHD, California Institute of Technology, 1986

Welch, George R, Professor
Physics & Astronomy
PHD, Massachusetts Institute of Technology, 1989

Wu, Wenhao, Associate Professor
Physics & Astronomy
PHD, University of Chicago, 1992

Zheltikov, Alexey M, Professor
Physics & Astronomy
PHD, M.V. Lomonosov Moscow State University, 1990

Zubairy, Muhammad S, Distinguished Professor
Physics & Astronomy
PHD, University of Rochester, 1979

Masters

- Master of Science in Astronomy (http://catalog.tamu.edu/graduate/colleges-schools-interdisciplinary/science/physics-astronomy/astronomy-ms)
- Master of Science in Physics (http://catalog.tamu.edu/graduate/colleges-schools-interdisciplinary/science/physics-astronomy/physics-ms)

Doctoral

- Doctor of Philosophy in Applied Physics (http://catalog.tamu.edu/graduate/colleges-schools-interdisciplinary/science/physics-astronomy/applied-physics-phd)
- Doctor of Philosophy in Astronomy (http://catalog.tamu.edu/graduate/colleges-schools-interdisciplinary/science/physics-astronomy/astronomy-phd)
- Doctor of Philosophy in Physics (http://catalog.tamu.edu/graduate/colleges-schools-interdisciplinary/science/physics-astronomy/physics-phd)

Courses

ASTR 600 Order-of-Magnitude Astrophysics
Credit 1. 1 Lecture Hour.
Introduction to the utility of order of magnitude calculations and the
ability to think intuitively; short overviews of basic physical concepts
followed by interactive activities and problem solving at the board.
Prerequisite: ASTR 314 or equivalent, or approval of instructor.

ASTR 601/PHYS 641 Extragalactic Astronomy
Credits 3. 3 Lecture Hours.
Overview of observations of galaxies and large-scale structures in the
Universe to understand their formation and evolution from theoretical
and observational perspectives; galaxy luminosity functions; evolution of
stellar populations and chemical enrichment; clusters and AGN.
Prerequisites: PHYS 601; or ASTR 314 and PHYS 302; or approval of
instructor.
Cross Listing: PHYS 641/ASTR 601.

ASTR 602/PHYS 642 Astronomical Observing Techniques and
Instrumentation
Credits 3. 3 Lecture Hours.
Theory and practice of obtaining and analyzing astrometric, photometric,
spectroscopic, and interferometric measurements of astronomical
sources across the electromagnetic spectrum; principles of design,
fabrication, assembly, test, deployment, and use of astronomical
instruments.
Prerequisites: PHYS 615 or equivalent; or approval of instructor.
Cross Listing: PHYS 642/ASTR 602.

ASTR 603/PHYS 643 Stellar Astrophysics
Credits 3. 3 Lecture Hours.
Theoretical and observational aspects of stellar astrophysics;
thermodynamic properties of stellar interiors; energy sources; nuclear
processes and burning stages; convective and radiative energy transport;
evolutionary models; atmospheres; stability and pulsations; chemical
enrichment processes; population synthesis.
Prerequisites: PHYS 606 and PHYS 607 or equivalents; or approval of
instructor.
Cross Listing: PHYS 643/ASTR 603.

ASTR 604/PHYS 644 Cosmology
Credits 3. 3 Lecture Hours.
Basic principles of modern cosmology and particle physics; general
relativity; cosmic inflation; Big Bang nucleosynthesis; expansion of the
universe; cosmic microwave background; large-scale structure of the
Universe; properties of particles; dark matter; dark energy.
Prerequisites: PHYS 615 or equivalent; or approval of instructor.
Cross Listing: PHYS 644/ASTR 604.
ASTR 605/PHYS 645 Galactic Astronomy
Credits 3.3 Lecture Hours.
Basic nature and structure of constituents of Milky Way galaxy; distribution and motions of stars and gas; origin evolution and distribution of large-scale chemical abundances and kinematic patterns across populations; models of galaxy formation and implications of modern observations.
Prerequisites: PHYS 601 and PHYS 607 or equivalents; or approval of instructor.
Cross Listing: PHYS 645/ASTR 605.

ASTR 606/PHYS 646 Radiative Transfer
Credits 3.3 Lecture Hours.
Fundamental radiative processes in stellar and planetary atmospheres; radiative fields; Stokes parameters; Mueller matrix formalism; radiation from moving charges; Compton scattering; plasma effects; atomic structure and radiative transitions; molecular structure and spectra; multiple scattering.
Prerequisites: PHYS 302, PHYS 304, PHYS 408, and PHYS 412 or equivalents; or approval of instructor.
Cross Listing: PHYS 646/ASTR 606.

ASTR 681 Seminar
Credit 1.1 Lecture Hour.
Subjects of current importance; normally required of all graduate students in astronomy. May be repeated for credit.

ASTR 685 Directed Studies
Credits 1 to 9.1 to 9 Other Hours.
Individual problems not related to thesis.
Prerequisite: Approval of instructor.

ASTR 689 Special Topics in...
Credits 1 to 4.1 to 4 Lecture Hours.
Selected topics in an identified area of astronomy. May be repeated for credit.
Prerequisite: Approval of instructor.

ASTR 691 Research
Credits 1 to 23.1 to 23 Other Hours.
Research toward thesis or dissertation.
Prerequisite: Baccalaureate degree in physics or equivalent.

PHYS 601 Analytical Mechanics
Credits 3.3 Lecture Hours.
Hamilton approaches to dynamics; canonical transformation and variational techniques; central force and rigid body motions; the mechanics of small oscillations and continuous systems.
Prerequisites: PHYS 302 or equivalent; MATH 311 and MATH 412 or equivalents; concurrent registration in PHYS 615.

PHYS 603 Electromagnetic Theory
Credits 3.3 Lecture Hours.
Boundary-value problems in electrostatics; basic magnetostatics; multipoles; elementary treatment of ponderable media; Maxwell’s equations for time-varying fields; energy and momentum of electromagnetic field; Poynting’s theorem; gauge transformations.
Prerequisites: PHYS 304 or equivalents; PHYS 615.

PHYS 606 Quantum Mechanics
Credits 3.3 Lecture Hours.
Schrödinger wave equation, bound states of simple systems, collision theory, representation and expansion theory, matrix formulation, perturbation theory.
Prerequisites: PHYS 412 or equivalent; MATH 311 and MATH 412 or equivalents; concurrent registration in PHYS 615.

PHYS 607 Statistical Mechanics
Credits 3.3 Lecture Hours.
Classical statistical mechanics, Maxwell-Boltzmann distribution, and equipartition theorem; quantum statistical mechanics, Bose-Einstein distribution and Fermi-Dirac distribution; applications such as polyatomic gases, blackbody radiation, free electron model for metals, Debye model of vibrations in solids, ideal quantum mechanical gases and Bose-Einstein condensation; if time permits, phase transitions and nonequilibrium statistical mechanics.
Prerequisites: PHYS 408 and PHYS 412 or equivalents; PHYS 615.

PHYS 611 Electromagnetic Theory
Credits 3.3 Lecture Hours.
Continuation of PHYS 603. Propagation, reflection and refraction of electromagnetic waves; wave guides and cavities; interference and diffraction; simple radiating systems; dynamics of relativistic particles and fields; radiation by moving charges.
Prerequisite: PHYS 603.

PHYS 615 Methods of Theoretical Physics I
Credits 3.3 Lecture Hours.
Orthogonal eigenfunctions with operator and matrix methods applied to solutions of the differential and integral equations of mathematical physics; contour integration, asymptotic expansions of Fourier transforms, the method of stationary phase and generalized functions applied to problems in quantum mechanics.
Prerequisites: MATH 311, MATH 407 and MATH 412 or equivalents.

PHYS 616 Methods of Theoretical Physics II
Credits 3.3 Lecture Hours.
Group theory and its implementation in physical systems; finite groups, Lie groups and Lie algebras; representation theory, symmetries of regular objects, global aspects of Lie groups and classification of Lie algebras.
Prerequisites: PHYS 615 or approval of instructor.

PHYS 617 Physics of the Solid State
Credits 3.3 Lecture Hours.
Crystalline structure and symmetry operations; electronic properties in the free electron model with band effects included; lattice vibrations and phonons; thermal properties; additional topics selected by the instructor from: scattering of X-rays, electrons, and neutrons, electrical and thermal transport, magnetism, superconductivity, defects, semiconductor devices, dielectrics, optical properties.
Prerequisites: PHYS 606 and PHYS 607.

PHYS 619 Modern Computational Physics
Credits 3.2 Lecture Hours. 2 Lab Hours.
Modern computational methods with emphasis on simulation such as molecular dynamics and Monte Carlo; applications to condensed matter and nuclear many-body physics and to lattice gauge theories.
Prerequisites: PHYS 408 and PHYS 412 or equivalents; knowledge of any programming language.

PHYS 624 Quantum Mechanics
Credits 3.3 Lecture Hours.
Continuation of PHYS 606. Scattering theory, second quantization, angular momentum theory, approximation methods, application to atomic and nuclear systems, semi-classical radiation theory.
Prerequisite: PHYS 606.

PHYS 625 Nuclear Physics
Credits 3.3 Lecture Hours.
Nuclear models, nuclear spectroscopy, nuclear reactions, electromagnetic properties of nuclei; topics of current interest.
Prerequisite: PHYS 606.
PHYS 627 Elementary Particle Physics
Credits 3. 3 Lecture Hours.
Fundamentals of elementary particle physics; particle classification, symmetry principles, relativistic kinematics and quark models; basics of strong, electromagnetic and weak interactions.
Prerequisite: PHYS 606.

PHYS 631 Quantum Theory of Solids
Credits 3. 3 Lecture Hours.
Second quantization, and topics such as plasmons; many-body effects for electrons; electron-phonon interaction; magnetism and magnons; other elementary excitations in solids; BCS theory of superconductivity; interactions of radiation with matter; transport theory in solids.
Prerequisites: PHYS 617 and PHYS 624.

PHYS 632 Condensed Matter Theory
Credits 3. 3 Lecture Hours.
Prerequisites: PHYS 601, PHYS 617 and PHYS 624.

PHYS 634 Relativistic Quantum Field Theory
Credits 3. 3 Lecture Hours.
Classical scalar, vector and Dirac fields; second quantization; scattering matrix and perturbation theory; dispersion relations; renormalization.
Prerequisite: PHYS 624.

PHYS 638 Quantum Field Theory II
Credits 3. 3 Lecture Hours.
Functional integrals; divergences, regularization and renormalization; non-abelian gauge theories; other topics of current interest.
Prerequisite: PHYS 634.

PHYS 639 Methods of Experimental Particle Physics
Credits 3. 2 Lecture Hours. 2 Lab Hours.
Methods of particle detection and data analysis techniques in experimental particle physics; computational and statistical methods in modern research; next challenges in experimental particle physics; use of statistical and computational techniques, Monte Carlo simulation methods, presenting and documenting scientific findings using LaTeX.
Prerequisites: PHYS 305 and PHYS 412; working knowledge of C or C++; or approval of instructor.

PHYS 641/ASTR 601 Extragalactic Astronomy
Credits 3. 3 Lecture Hours.
Overview of observations of galaxies and large-scale structures in the Universe to understand their formation and evolution from theoretical and observational perspectives; galaxy luminosity functions; evolution of stellar populations and chemical enrichment; clusters and AGN.
Prerequisites: PHYS 601; or ASTR 314 and PHYS 302; or approval of instructor.
Cross Listing: ASTR 601/PHYS 641.

PHYS 642/ASTR 602 Astronomical Observing Techniques and Instrumentation
Credits 3. 3 Lecture Hours.
Theory and practice of obtaining and analyzing astrometric, photometric, spectroscopic, and interferometric measurements of astronomical sources across the electromagnetic spectrum; principles of design, fabrication, assembly, test, deployment, and use of astronomical instruments.
Prerequisites: PHYS 615 or equivalent; or approval of instructor.
Cross Listing: ASTR 602/PHYS 642.

PHYS 643/ASTR 603 Stellar Astrophysics
Credits 3. 3 Lecture Hours.
Theoretical and observational aspects of stellar astrophysics; thermodynamic properties of stellar interiors; energy sources; nuclear processes and burning stages; convective and radiative energy transport; evolutionary models; atmospheres; stability and pulsations; chemical enrichment processes; population synthesis.
Prerequisites: PHYS 606 and PHYS 607 or equivalents; or approval of instructor.
Cross Listing: ASTR 603/PHYS 643.

PHYS 644/ASTR 604 Cosmology
Credits 3. 3 Lecture Hours.
Basic principles of modern cosmology and particle physics; general relativity; cosmic inflation; Big Bang nucleosynthesis; expansion of the universe; cosmic microwave background; large-scale structure of the Universe; properties of particles; dark matter; dark energy.
Prerequisites: PHYS 615 or equivalent; or approval of instructor.
Cross Listing: ASTR 604/PHYS 644.

PHYS 645/ASTR 605 Galactic Astronomy
Credits 3. 3 Lecture Hours.
Basic nature and structure of constituents of Milky Way galaxy; distribution and motions of stars and gas; origin evolution and distribution of large-scale chemical abundances and kinematic patterns across populations; models of galaxy formation and implications of modern observations.
Prerequisites: PHYS 601 and PHYS 607 or equivalents; or approval of instructor.
Cross Listing: ASTR 605/PHYS 645.

PHYS 646/ASTR 606 Radiative Transfer
Credits 3. 3 Lecture Hours.
Fundamental radiative processes in stellar and planetary atmospheres; radiative fields; Stokes parameters; Mueller matrix formalism; radiation from moving charges; Compton scattering; plasma effects; atomic structure and radiative transitions; molecular structure and spectra; multiple scattering.
Prerequisites: PHYS 302, PHYS 304, PHYS 408, and PHYS 412 or equivalents; or approval of instructor.
Cross Listing: ASTR 606/PHYS 646.

PHYS 647 Gravitational Physics
Credits 3. 3 Lecture Hours.
Special relativity; equivalence principle; theory of gravitation; Einstein's theory of general relativity; classic tests of general relativity; simple black hole and cosmological solutions; global aspects; penrose diagrams; stationary black holes; Hawking radiation.
Prerequisites: PHYS 611 and PHYS 615.
PHYS 648 Quantum Optics and Laser Physics  
Credits 3. 3 Lecture Hours.  
Line widths of spectral lines; laser spectroscopy; optical cooling; trapping of atoms and ions; coherence; pico- and femto-second spectroscopy; spectroscopic instrumentation.  
Prerequisite: Approval of instructor.  

PHYS 649 Physics of Optoelectronic Devices  
Credits 3. 3 Lecture Hours.  
Overview of basic concepts: laser physics, optics of semiconductors, heterostructures with quantum confinement and their interaction with light; physical principles of state of the art optoelectronic devices; emerging concepts and technologies: integrated photonics, nanophotonics, plasmonics, metamaterials, terahertz optoelectronics, quantum information processing, etc.  
Prerequisites: Quantum mechanics (PHYS 412 and PHYS 414 or PHYS 606 or equivalent).  

PHYS 651 Superstring Theory I  
Credits 3. 3 Lecture Hours.  
Basics of string theory, including bosonic string, conformal field theory, strings with worldsheets and space-time supersymmetry, and as well as the higher dimensional extended objects called D-branes.  
Prerequisites: PHYS 634 and PHYS 653; PHYS 647 recommended.  

PHYS 652 Superstring Theory II  
Credits 3. 3 Lecture Hours.  
M-theory unification of superstring theories into a single eleven-dimensional theory; duality symmetries relating string theories; string geometry; Calabi-Yau manifolds and exceptional holonomy manifolds; flux compactifications; black holes in string theory; AdS/CFT correspondence; string and M-theory cosmology.  
Prerequisites: PHYS 651; PHYS 647 recommended.  

PHYS 653 Introduction to Supersymmetry and Supergravity  
Credits 3. 3 Lecture Hours.  
Core material on supersymmetric field theories and their coupling to supergravity theories.  
Prerequisite: PHYS 634.  

PHYS 654 The Standard Model and Beyond  
Credits 3. 3 Lecture Hours.  
The standard model of particle physics in detail; general principles of gauge theories, including spontaneous breaking and applications to Electro-Weak Interactions and Quantum Chromodynamics; extension of the standard model involving Grand Unified Theories (GUT), Supersymmetry (SUSY) and Supergravity (SUGRA).  
Prerequisites: PHYS 624 and PHYS 634.  

PHYS 655 String Phenomenology  
Credits 3. 3 Lecture Hours.  
Physical applications of string theory; rudiments of string theory; compactification of extreme dimensions in string theory; free-fermionic formulation; dualities, M-theory, intersection D-Branes, and D-Brane phenomenology; model building.  
Prerequisites: PHYS 634 and PHYS 651.  

PHYS 666 Scientific Instrument Making  
Credits 3. 2 Lecture Hours. 2 Lab Hours.  
Theory and techniques for designing and constructing advanced scientific instruments such as spectrometers, cryostats, vacuum systems, etc.; mechanical and electronic shop procedures utilizing the lathe and mill; welding and soldering; drafting and print reading; circuit design.  
Prerequisite: Approval of instructor.  

PHYS 671 Ultrafast Laser Physics  
Credits 3. 3 Lecture Hours.  
Ultrafast optics; nonlinear optics; laser physics; active and passive modellocking; pulse characterization and shaping; applications in industry and research such as time-resolved spectroscopy, coherent control, terahertz spectroscopy, and high-order harmonic generation.  
Prerequisites: PHYS 204, PHYS 205, PHYS 221 and PHYS 412, or equivalents.  

PHYS 674/ECEN 674 Introduction to Quantum Computing  
Credits 3. 3 Lecture Hours.  
Introduces the quantum mechanics, quantum gates, quantum circuits and quantum hardware of potential quantum computers; algorithms, potential uses, complexity classes, and evaluation of coherence of these devices.  
Prerequisites: MATH 304; PHYS 208.  
Cross Listing: ECEN 674/PHYS 674.  

PHYS 681 Seminar  
Credit 1. 1 Lecture Hour.  
Subjects of current importance; normally required of all graduate students in physics.  

PHYS 685 Directed Studies  
Credits 1 to 9. 1 to 9 Other Hours.  
Individual problems not related to thesis.  
Prerequisite: Approval of instructor.  

PHYS 689 Special Topics in...  
Credits 1 to 4. 1 to 4 Lecture Hours. 0 to 4 Lab Hours.  
Selected topics in an identified area of physics. May be repeated for credit.  
Prerequisite: Approval of instructor.  

PHYS 691 Research  
Credits 1 to 23. 1 to 23 Other Hours.  
Research toward thesis or dissertation.  
Prerequisite: Baccalaureate degree in physics or equivalent.