PHYSICS (PHGN)

PHGN100. PHYSICS I - MECHANICS. 4.0 Semester Hrs.
A first course in physics covering the basic principles of mechanics using vectors and calculus. The course consists of a fundamental treatment of the concepts and applications of kinematics and dynamics of particles and systems of particles, including Newton's laws, energy and momentum, rotation, oscillations, and waves. Approved for Colorado Guaranteed General Education transfer. Equivalency for GT-SC1. Prerequisite: MATH111. Co-requisite: MATH112 or MATH122.
Course Learning Outcomes

- No change

PHGN198. SPECIAL TOPICS. 1-6 Semester Hr.
(I, II) Pilot course or special topics course. Prerequisite: none. Credit to be determined by instructor, maximum of 6 credit hours. Repeatable for credit under different titles.

PHGN199. INDEPENDENT STUDY. 1-6 Semester Hr.
(I,II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: Independent Study form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

PHGN200. PHYSICS II-ELECTROMAGNETISM AND OPTICS. 4.0 Semester Hrs.
Continuation of PHGN100. Introduction to the fundamental laws and concepts of electricity and magnetism, electromagnetic devices, electromagnetic behavior of materials, applications to simple circuits, electromagnetic radiation, and an introduction to optical phenomena. Prerequisite: Grade of C- or higher in PHGN100. Co-requisite: MATH213 or MATH223.

PHGN215. ANALOG ELECTRONICS. 4.0 Semester Hrs.
Introduction to analog devices used in modern electronics and basic topics in electrical engineering. Introduction to methods of electronics measurements, particularly the application of oscilloscopes and computer based data acquisition. Topics covered include circuit analysis, electrical power, diodes, transistors (FET and BJT), operational amplifiers, filters, transducers, and integrated circuits. Laboratory experiments in the use of basic electronics for physical measurements. Emphasis is on practical knowledge gained in the laboratory, including prototyping, troubleshooting, and laboratory notebook style. 3 hours lecture, 3 hours lab; 4 semester hours. Prerequisite: PHGN200.

PHGN298. SPECIAL TOPICS. 1-6 Semester Hr.
(I, II) Pilot course or special topics course. Prerequisite: none. Credit to be determined by instructor, maximum of 6 credit hours. Repeatable for credit under different titles.

PHGN299. INDEPENDENT STUDY. 1-6 Semester Hr.
(I,II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: Independent Study form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

PHGN300. PHYSICS III-MODERN PHYSICS I. 3.0 Semester Hrs.
Equivalent with PHGN310,
Our technical world is filled with countless examples of modern physics. This course will discuss some historic experiments that led to the key discoveries, and the basic concepts, theories, and models behind some of our present day technologies. Topics may include special relativity, quantum physics, atomic and molecular physics, solid-state physics, semiconductor theory and devices, nuclear physics, particle physics and cosmology. 3 hours lecture; 3 semester hours. Prerequisite: PHGN200; Concurrent enrollment in MATH225.

PHGN310. HONORS PHYSICS III-MODERN PHYSICS. 3.0 Semester Hrs.
Equivalent with PHGN300,
The third course in introductory physics with in depth discussion on special relativity, wave-particle duality, the Schroedinger equation, electrons in solids, quantum tunneling, nuclear structure and transmutations. Registration is strongly recommended for declared physics majors and those considering majoring or minoring in physics. 3 hours lecture; 3 semester hours. Prerequisite: PHGN200; Concurrent enrollment in MATH225.

PHGN311. INTRODUCTION TO MATHEMATICAL PHYSICS. 3.0 Semester Hrs.
Demonstration of the unity of diverse topics such as mechanics, quantum mechanics, optics, and electricity and magnetism via the techniques of linear algebra, complex variables, Fourier transforms, and vector calculus. 3 hours lecture; 3 semester hours. Prerequisite: PHGN300 or PHGN310, MATH225, MATH332, and CSCI250.
Course Learning Outcomes

- Given some data, immediately have a set of analysis tools you can use to understand the physics behind it.
- Given a modeling problem, be able to reach into your mathematical toolbox and solve it at least three ways, developing different lines of evidence.
- Given a mathematical technique or idea, be able to understand the deep concepts underlying it and provide a clear physical example.

PHGN315. ADVANCED PHYSICS LAB I. 2.0 Semester Hrs.
(WI) Introduction to laboratory measurement techniques as applied to modern physics experiments. Experiments from optics and atomic physics. A writing-intensive course with laboratory and computer design projects based on applications of modern physics. 1 hour lecture, 3 hours lab; 2 semester hours. Prerequisite: PHGN300/310, PHGN384.

PHGN317. SEMICONDUCTOR CIRCUITS- DIGITAL. 3.0 Semester Hrs.
Introduction to digital devices used in modern electronics. Topics covered include logic gates, flip-flops, timers, counters, multiplexing, analog-to-digital and digital-to-analog devices. Emphasis is on practical circuit design and assembly. Prerequisite: PHGN215 and CSCI250. 2 hours lecture; 3 hours lab; 3 semester hours.
Course Learning Outcomes

- 1. To understand the basics of digital electronics commonly used as part of instrumentation used in physical measurements.
- 2. To be able to construct and recognize combinational and sequential circuits, understand and implement simple state machine design principles in circuit design.
- 3. To be familiar with common techniques, interfaces and tools used in data acquisition.
- 4. Combine these topics to produce a viable microntroller system capable of making physical measurements.

PHGN320. MODERN PHYSICS II: BASICS OF QUANTUM MECHANICS. 4.0 Semester Hrs.
Introduction to the Schroedinger theory of quantum mechanics. Topics include Schroedinger's equation, quantum theory of measurement, the uncertainty principle, eigenfunctions and energy spectra, anular

momentum, perturbation theory, and the treatment of identical particles. Example applications taken from atomic, molecular, solid state or nuclear systems. 4 hours lecture; 4 semester hours. Prerequisite: MATH332, MATH342.

PHGN324. INTRODUCTION TO ASTRONOMY AND ASTROPHYSICS. 3.0 Semester Hrs.
Celestial mechanics; Kepler's laws and gravitation; solar system and its contents; electromagnetic radiation and matter; stars: distances, magnitudes, spectral classification, structure, and evolution. Variable and unusual stars, pulsars and neutron stars, supernovae, black holes, and models of the origin and evolution of the universe. 3 hours lecture; 3 semester hours. Prerequisite: PHGN200.
Course Learning Outcomes

- No change

PHGN326. ADVANCED PHYSICS LAB II. 2.0 Semester Hrs.
(WI) Continuation of PHGN315. A writing-intensive course which expands laboratory experiments to include nuclear and solid state physics. 1 hour lecture, 3 hours lab; 2 semester hours. Prerequisite: PHGN315.

PHGN340. COOPERATIVE EDUCATION. 1-3 Semester Hr.
(I, II, S) Supervised, full-time, engineering-related employment for a continuous six-month period (or its equivalent) in which specific educational objectives are achieved. Prerequisite: Second semester sophomore status and a cumulative grade-point average of at least 2.00. 1 to 3 semester hours. Repeatable up to 3 credit hours.

PHGN341. THERMAL PHYSICS. 3.0 Semester Hrs.
An introduction to statistical physics from the quantum mechanical point of view. The microcanonical and canonical ensembles. Heat, work and the laws of thermodynamics. Thermodynamic potentials; Maxwell relations; phase transformations. Elementary kinetic theory. An introduction to quantum statistics. 3 hours lecture; 3 semester hours. Prerequisite: CHGN122 or CHGN125 and PHGN311.
Course Learning Outcomes

- Demonstrate an understanding of the microscopic statistical framework for the thermodynamic properties of systems with a large number of particles
- Demonstrate an understanding of the laws of thermodynamics, their applications, and their justication through statistical physics
- Construct an appropriate understanding of thermodynamic phenomena in an applied context
- Develop communication, teamwork, and leadership skills through group activities

PHGN350. INTERMEDIATE MECHANICS. 4.0 Semester Hrs.
Begins with an intermediate treatment of Newtonian mechanics and continues through an introduction to Hamilton's principle and Hamiltonian and Lagrangian dynamics. Includes systems of particles, linear and driven oscillators, motion under a central force, two-particle collisions and scattering, motion in non-inertial reference frames and dynamics of rigid bodies. 4 hours lecture; 4 semester hours. Prerequisite: PHGN200. Co-requisite: PHGN311.
Course Learning Outcomes

- No change

PHGN361. INTERMEDIATE ELECTROMAGNETISM. 3.0 Semester Hrs.
Theory and application of the following: static electric and magnetic fields in free space, dielectric materials, and magnetic materials; steady currents; scalar and vector potentials; Gauss' law and Laplace's equation applied to boundary value problems; Ampere's and Faraday's laws. 3 hours lecture; 3 semester hours. Prerequisite: PHGN200 and PHGN311.
Course Learning Outcomes

- No change

PHGN384. FIELD SESSION TECHNIQUES IN PHYSICS. 1-6 Semester Hr.
Introduction to the design and fabrication of engineering physics apparatus. Intensive individual participation in the design of machined system components, vacuum systems, electronics, optics, and application of computer interfacing systems and computational tools. Supplementary lectures on safety, laboratory techniques and professional development. Visits to regional research facilities and industrial plants. Prerequisites: PHGN300 or PHGN310, PHGN215, CSCI250. 6 semester hours.
Course Learning Outcomes

- 1. to give students a working knowledge of the practical aspects of materials, instrumentation and phenomena associated with laboratory practice
- 2. to train students in the use of important experimental and data analysis devices and tools
- 3. to show students how working physicists operate and to help them achieve professional standards in work practice and communication

PHGN398. SPECIAL TOPICS. 1-6 Semester Hr.
(I, II) Pilot course or special topics course. Prerequisite: none. Credit to be determined by instructor, maximum of 6 credit hours. Repeatable for credit under different titles.

PHGN399. INDEPENDENT STUDY. 1-6 Semester Hr.
(I,II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: Independent Study form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

PHGN401. PHYSICS SEMINAR. 1.0 Semester Hr.
Students will attend the weekly physics seminar. Students will be responsible for presentation and discussion. Co-requisite: PHGN300 or PHGN310.

PHGN417. FUNDAMENTALS OF QUANTUM INFORMATION. 3.0 Semester Hrs.
This course serves as a broad introduction to quantum information science, open to students from many backgrounds. The basic structure of quantum mechanics (Hilbert spaces, operators, wavefunctions, entanglement, superposition, time evolution) is presented, as well as a number of important topics relevant to current quantum hardware (including oscillating fields, quantum noise, and more). Finally, we will survey the gate model of quantum computing, and study the critical subroutines which provide the promise of a quantum speedup in future quantum computers. Prerequisite: MATH332 or MATH342.
Course Learning Outcomes

- 1. Construct Hilbert spaces, operators, wavefunctions and predict the outcome of measurements
- 2. Identify the key ways in which quantum mechanics differs from classical mechanics: entanglement and superposition
- 3. Simulate time evolution in quantum systems
- 4. Diagonalize simple quantum Hamiltonians and predict their spectra

- 5. Simulate oscillating fields in quantum systems
- 6. Implement simple calculations using the gate model of quantum computing. They will also learn how to use ancilla qubits, and how to construct arbitrary operations from one- and two-qubit gates
- 7. Identify mechanisms for a quantum speedup in quantum algorithms, learned through a survey of some of the most famous ones

PHGN418. GENERAL RELATIVITY. 3.0 Semester Hrs.
Introduction to Einstein's theory of gravitation. Requisite mathematics introduced and developed including tensor calculus and differential geometry. Formulation of Einstein field and geodesic equations. Development and analysis of solutions including stellar, black hole and cosmological geometries. Prerequisite: PHGN350. 3 hours lecture; 3 semester hours.
Course Learning Outcomes

- No change

PHGN419. PRINCIPLES OF SOLAR ENERGY SYSTEMS. 3.0 Semester Hrs.
Review of the solar resource and components of solar irradiance; principles of photovoltaic devices and photovoltaic system design; photovoltaic electrical energy production and cost analysis of photovoltaic systems relative to fossil fuel alternatives; introduction to concentrated photovoltaic systems and manufacturing methods for wafer-based and thin film photovoltaic panels. Prerequisite: PHGN200 and MATH225. 3 hours lecture; 3 semester hours.

PHGN422. NUCLEAR PHYSICS. 3.0 Semester Hrs.
Introduction to subatomic (particle and nuclear) phenomena. Characterization and systematics of particle and nuclear states; symmetries; introduction and systematics of the electromagnetic, weak, and strong interactions; systematics of radioactivity; liquid drop and shell models; nuclear technology. Prerequisite: PHGN300/310. 3 hours lecture; 3 semester hours.

PHGN423. PARTICLE PHYSICS. 3.0 Semester Hrs.
Introduction to the Standard Model of particle physics including: experimental methods, motivation and evaluation of amplitudes from Feynman diagrams with applications to scattering cross-sections and decay rates, organization of interactions based on underlying gauge-symmetry principles, Dirac equation and relativistic spinors, C, P and T symmetries, renormalization, spontaneous symmetry breaking and the Higgs mechanism for mass generation. Prerequisites: PHGN350. Co-requisites: PHGN320. 3 hour lecture.

PHGN424. ASTROPHYSICS. 3.0 Semester Hrs.
A survey of fundamental aspects of astrophysical phenomena, concentrating on measurements of basic stellar properties such as distance, luminosity, spectral classification, mass, and radii. Simple models of stellar structure evolution and the associated nuclear processes as sources of energy and nucleosynthesis. Introduction to cosmology and physics of standard big-bang models. Prerequisite: PHGN300/310. 3 hours lecture; 3 semester hours.

PHGN433. BIOPHYSICS. 3.0 Semester Hrs.
Equivalent with PHGN333,
This course is designed to show the application of physics to biology. It will assess the relationships between sequence structure and function in complex biological networks and the interfaces between physics, chemistry, biology and medicine. Topics include: biological membranes, biological mechanics and movement, neural networks, medical imaging basics including optical methods, MRI, isotopic tracers and CT, biomagnetism and pharmacokinetics. Prerequisites: CBEN110. 3 hours lecture; 3 semester hours.
Course Learning Outcomes

- 1. To simulate and analyze random biological processes.
- 2. Ability to apply the principles learned in the course to contemporary research topic.
- 3. To understand the concepts of free energy and how it relates to the speed and spontaneity of chemical reactions.
- 4. Ability to work and communicate with others.
- 5. To analyze and solve problems independently.

PHGN435. INTERDISCIPLINARY MICROELECTRONICS PROCESSING LABORATORY. 3.0 Semester Hrs.
Equivalent with CBEN435,CBEN535,CHEN435,CHEN535,MLGN535,PHGN535,
Application of science and engineering principles to the design, fabrication, and testing of microelectronic devices. Emphasis on specific unit operations and the interrelation among processing steps. Prerequisite: MATH213 or MATH223.

PHGN440. SOLID STATE PHYSICS. 3.0 Semester Hrs.
An elementary study of the properties of solids including crystalline structure and its determination, lattice vibrations, electrons in metals, and semiconductors. 3 hours lecture; 3 semester hours. Prerequisite: PHGN320.

PHGN441. SOLID STATE PHYSICS APPLICATIONS AND PHENOMENA. 3.0 Semester Hrs.
Continuation of PHGN440/ MLGN502 with an emphasis on applications of the principles of solid state physics to practical properties of materials including: optical properties, superconductivity, dielectric properties, magnetism, noncrystalline structure, and interfaces. (Graduate students in physics may register only for PHGN441.) Prerequisite: PHGN440 or MLGN502. 3 hours lecture; 3 semester hours.

PHGN450. COMPUTATIONAL PHYSICS. 3.0 Semester Hrs.
Introduction to numerical methods for analyzing advanced physics problems. Topics covered include finite element methods, analysis of scaling, efficiency, errors, and stability, as well as a survey of numerical algorithms and packages for analyzing algebraic, differential, and matrix systems. The numerical methods are introduced and developed in the analysis of advanced physics problems taken from classical physics, astrophysics, electromagnetism, solid state, and nuclear physics. Prerequisites: Introductory-level knowledge of C, Fortran, or Basic; and PHGN311. 3 hours lecture; 3 semester hours.

PHGN461. ELEMENTS OF MODERN OPTICS. 3.0 Semester Hrs.
This course is designed to prepare students for a variety of goals including enrollment in advanced optics courses and research in both academia and industry. Topics covered in the course will provide foundational skills vital to all areas of optics and include the use of complex phasor notation, solutions to the wave equation, electromagnetic energy flow, the interaction of electromagnetic energy with matter, light propagation (through lenses, stops, mirrors, prisms, and fiber optics), as well as the effects of polarizers, birefringent materials, and retarders in optical system designs. Prerequisite: PHGN311.
Course Learning Outcomes

- 1. Use complex phasor notation, understand solutions to the Wave Equation, identify what phase is and its relationship with superposition.

- 2. Using basic laws of electricity and magnetism, calculate the direction and magnitude of electromagnetic energy flow including its interaction with matter.
- 3. Form a mathematical description of light propagation.
- 4. Use concepts from light propagation to analyze optical systems containing lenses, stops, mirrors, prisms, and fiber optics.
- 5. Explain the effects polarizers, birefringence, and retarders on light using Jones and Mueller matrix formalism.

PHGN462. ELECTROMAGNETIC WAVES AND OPTICAL PHYSICS. 3.0 Semester Hrs.
Solutions to the electromagnetic wave equation, including plane waves, guided waves, refraction, interference, diffraction and polarization; applications in optics; imaging, lasers, resonators and wave guides. 3 hours lecture; 3 semester hours. Prerequisite: PHGN361.

PHGN466. MODERN OPTICAL ENGINEERING. 3.0 Semester Hrs.
Provides students with a comprehensive working knowledge of optical system design that is sufficient to address optical problems found in their respective disciplines. Topics include paraxial optics, imaging, aberration analysis, use of commercial ray tracing and optimization, diffraction, linear systems and optical transfer functions, detectors and optical system examples.

PHGN471. SENIOR DESIGN PRINCIPLES I. 0.5 Semester Hrs.
(WI) The first of a two semester sequence covering the principles of project design. Class sessions cover effective team organization, project planning, time management, literature research methods, record keeping, fundamentals of technical writing, professional ethics, project funding and intellectual property. Prerequisites: PHGN384 and PHGN326. Co-requisites: PHGN481 or PHGN491. 1 hour lecture in 7 class sessions; 0.5 semester hours.

PHGN472. SENIOR DESIGN PRINCIPLES II. 0.5 Semester Hrs.
(WI) Continuation of PHGN471. Prerequisite: PHGN384 and PHGN326. Co-requisite: PHGN482 or PHGN492. 1 hour lecture in 7 class sessions; 0.5 semester hours.

PHGN480. LASER PHYSICS. 3.0 Semester Hrs.
Theory and application of the following: Interaction of light with atoms: absorption, gain, rate equations and line broadening. Propagation, control and measurement of light waves: Gaussian beams, optical resonators and wave guides, interferometers. Laser design and operation: pumping, oscillation, and dynamics (Q-switching and mode-locking). Introduction to ultrafast optics. Laboratory: alignment and characterization of laser systems. Prerequisites: PHGN320. Co-requisites: PHGN462. 3 hours lecture; 3 semester hours.
Course Learning Outcomes

- 1. understand the interaction of light with quantum transitions, including the origin of gain in different media
- 2. understand how to derive rate equations to describe the balance of stored energy in the gain medium and in the circulating light field in the resonator
- 3. understand how to use matrix methods to calculate the propagation of light as rays and as Gaussian beams and how to use these matrices to design optical resonators
- 4. understand how to build and apply a quantitative model of laser oscillation to a real laser system
- 5. be able to experimentally align and characterize simple lasers and interferometers
- 6. apply the principles of the course to a case study of a laser system

PHGN481. SENIOR DESIGN PRACTICE. 2.5 Semester Hrs.
(WI) The first of a two semester program covering the full spectrum of project design, drawing on all of the student's previous course work. At the beginning of the first semester, the student selects a research project in consultation with the Senior Design Oversight Committee (SDOC) and the Project Mentor. The objectives of the project are given to the student in broad outline form. The student then designs the entire project, including any or all of the following elements as appropriate: literature search, specialized apparatus or algorithms, block-diagram electronics, computer data acquisition and/or analysis, sample materials, and measurement and/or analysis sequences. The course culminates in a formal interim written report. Prerequisite: PHGN384 and PHGN326. Co-requisite: PHGN471. 6 hour lab; 2.5 semester hours.

PHGN482. SENIOR DESIGN PRACTICE. 2.5 Semester Hrs.
(WI) Continuation of PHGN481. The course culminates in a formal written report and poster. Prerequisite: PHGN384 and PHGN326. Co-requisite: PHGN472. 6 hour lab; 2.5 semester hours.

PHGN491. HONORS SENIOR DESIGN PRACTICE. 2.5 Semester Hrs.
(WI) Individual work on an advanced research topic that involves more challenging demands than a regular senior design project. Honors students will devote more time to their project, and will produce an intermediate report in a more advanced format. Prerequisite: PHGN384 and PHGN326. Corequisite: PHGN471. 7.5 hour lab; 2.5 semester hours.

PHGN492. HONORS SENIOR DESIGN PRACTICE. 2.5 Semester Hrs.
(WI) Continuation of PHGN481 or PHGN491. The course culminates in a formal written report and poster. The report may be in the form of a manuscript suitable for submission to a professional journal. Prerequisite: PHGN481 or PHGN491. Corequisite: PHGN472. 7.5 hour lab; 2.5 semesterhours.

PHGN498. SPECIAL TOPICS. 1-6 Semester Hr.
(I, II) Pilot course or special topics course. Prerequisite: none. Credit to be determined by instructor, maximum of 6 credit hours. Repeatable for credit under different titles.

PHGN498. SPECIAL TOPICS. 1-6 Semester Hr.
This course is designed for anyone interested in teaching physics at either the college or high school level. Topics include teaching methods for class time, recitation, labs, and homework. Students will engage directly with these methods as well as read the literature supporting each. Additionally time will be spent on assessment, both formative and summative; how to probe student thinking, what they are learning each class period, and what they have learned by the end of the term.

PHGN499. INDEPENDENT STUDY. 0.5-6 Semester Hr.
(I,II) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: Independent Study form must be completed and submitted to the Registrar. Variable credit; 1 to 6 credit hours. Repeatable for credit.

PHGN501. GRADUATE SEMINAR. 1.0 Semester Hr.
(I) M.S. students will attend the weekly Physics Colloquium. Students will be responsible for presentations during this weekly seminar. See additional course registration instructions under Program Requirements above. 1 hour seminar; 1 semester hour.

PHGN502. GRADUATE SEMINAR. 1.0 Semester Hr.
(II) M.S. students will attend the weekly Physics Colloquium. Students will be responsible for presentations during this weekly seminar. See additional course registration instructions under Program Requirements above. 1 hour seminar; 1 semester hour.

PHGN503. RESPONSIBLE CONDUCT OF RESEARCH. 1.0 Semester Hr.
(II) This course introduces students to the various components of responsible research practices. Subjects covered move from issues related to professional rights and obligations through those related to collaboration, communication and the management of grants, to issues dealing with intellectual property. The course culminates with students writing an ethics essay based on a series of topics proposed by the course instructor. 1 hour lecture; 1 semester hour.
Course Learning Outcomes

- To be: (1) Exposed to and able to address a broad range of ethical issues that arise in a professional career in science and engineering. (2) Able to discuss such issues in the context of basic ethical theories. (3) Conscious of ethical ideals and commitments as they relate to science, society, enterprise, and environment.

PHGN504. RADIATION DETECTION AND MEASUREMENT. 3.0 Semester Hrs.
Physical principles and methodology of the instrumentation used in the detection and measurement of ionizing radiation. Prerequisite: none. 3 hours lecture; 3 semester hours.

PHGN505. CLASSICAL MECHANICS I. 3.0 Semester Hrs.
(I) Review of Lagrangian and Hamiltonian formulations in the dynamics of particles and rigid bodies; kinetic theory; coupled oscillations and continuum mechanics; fluid mechanics. Prerequisite: PHGN350 or equivalent. 3 hours lecture; 3 semester hours.

PHGN507. ELECTROMAGNETIC THEORY I. 3.0 Semester Hrs.
(II) To provide a strong background in electromagnetic theory. Electrostatics, magnetostatics, dynamical Maxwell equations, wave phenomena. Prerequisite: PHGN462 or equivalent and PHGN511. 3 hours lecture; 3 semester hours.

PHGN511. MATHEMATICAL PHYSICS. 3.0 Semester Hrs.
(I) Review of complex variable and finite and infinite-dimensional linear vector spaces. Sturm-Liouville problem, integral equations, computer algebra. Prerequisite: PHGN311 or equivalent. 3 hours lecture; 3 semester hours.

PHGN515. GRADUATE LABORATORY. 3.0 Semester Hrs.
Hands-on, laboratory skills are fundamental to all career pathways for physics graduates. This course is designed to provide first year graduate students with introductory skills necessary to carry out research in discipline specific laboratories ? both in the physics department and post-graduate career settings. The course covers laboratory safety and current experiment best practices. Instruments common in academia, industry, and national labs are reviewed in their function and properties. Students will review experimental data analysis, error analysis, and error propagation concepts before applying them to experiments. Two weeks are dedicated to a student-facilitator shared experiment focusing on lock-in detection where students will learn the structure of note taking and grading. Students will then use what they learned in the lectures and tutorials to perform three experiments they help design. Although experimental results are expected and required, the course will emphasize scientific note taking and thought process over results. The experiments are intentionally open ended so students will have to think critically about their experimental methods, take detailed notes, and use trial-and-error. Thought process will be operationally defined through tinkering, resilience, teamwork, and communication.
Course Learning Outcomes

- Learning Outcomes

PHGN519. FUNDAMENTALS OF QUANTUM INFORMATION. 3.0 Semester Hrs.
This course serves as a broad introduction to quantum information science, open to students from many backgrounds. The basic structure of quantum mechanics (Hilbert spaces, operators, wavefunctions, entanglement, superposition, time evolution) is presented, as well as a number of important topics relevant to current quantum hardware (including oscillating fields, quantum noise, and more). Finally, we will survey the gate model of quantum computing, and study the critical subroutines which provide the promise of a quantum speedup in future quantum computers. Prerequisite: MATH332 (linear algebra) or an equivalent linear algebra course.
Course Learning Outcomes

- After completing this course, students will be able to: 1. Construct Hilbert spaces, operators, wavefunctions and predict the outcome of measurements
- 2. Identify the key ways in which quantum mechanics differs from classical mechanics: entanglement and superposition
- 3. Simulate time evolution in quantum systems
- 4. Diagonalize simple quantum Hamiltonians and predict their spectra
- 5. Simulate oscillating fields in quantum systems
- 6. Implement simple calculations using the gate model of quantum computing. They will also learn how to use ancilla qubits, and how to construct arbitrary operations from one- and two-qubit gates
- 7. Identify mechanisms for a quantum speedup in quantum algorithms, learned through a survey of some of the most famous ones

PHGN520. QUANTUM MECHANICS I. 3.0 Semester Hrs.
(II) Schroedinger equation, uncertainty, change of representation, one-dimensonal problems, axioms for state vectors and operators, matrix mechanics, uncertainty relations, time-independent perturbation theory, time-dependent perturbations, harmonic oscillator, angular momentum; semiclassical methods, variational methods, two-level system, sudden and adiabatic changes, applications. Prerequisite: PHGN511 and PHGN320 or equivalent. 3 hours lecture; 3 semester hours.

PHGN521. QUANTUM MECHANICS II. 3.0 Semester Hrs.
(I) Review of angular momentum, central potentials and applications. Spin; rotations in quantum mechanics. Formal scattering theory, Born series, partial wave analysis. Addition of angular momenta, Wigner-Eckart theorem, selection rules, identical particles. Prerequisite: PHGN520. 3 hours lecture; 3 semester hours.

PHGN530. STATISTICAL MECHANICS. 3.0 Semester Hrs.
(I) Review of thermodynamics; equilibrium and stability; statistical operator and ensemblesl ideal systems; phase transitions; non-equilibrium systems. Prerequisite: PHGN341 or equivalent and PHGN520. Co-requisite: PHGN521. 3 hours lecture; 3 semester hours.

PHGN532. LOW TEMPERATURE MICROWAVE MEASUREMENTS FOR QUANTUM ENGINEERING. 3.0 Semester Hrs.
The goal of the course is to provide hands on training in high-frequency, low-temperature measurements which are requisite for quantum information applications. This course introduces the fundamentals of high-frequency measurements, the latest techniques for accuracy-enhanced automated microwave measurements, low-temperature measurement techniques, low noise measurements, and common devices used in quantum information. The course will have three modules. The first module, basics of electronic measurements, will include chip layout, power measurements, ground loop testing, impedance measurements, noise fundamentals, cable and device

fabrication and care. The second module, high frequency measurements, will include measurements of basic scattering parameters, accuracy enhancement and calibration, transmission line, amplifier, and oscillator characterization including noise measurements. The third module, low-temperature measurements, will cover critical parameters for superconductors and Josephson junctions, measurements of superconducting resonators, characterization of low-temperature electronic elements including amplifiers. At the end of this course the students will know how to use network analyzers, spectrum analyzers, cryostats, the software Eagle for chip design, amplifiers, and filters.

Course Learning Outcomes

- 1. Describe key RF, wireless and microwave measurement parameters
- 2. Understand how to use a range of RF, wireless and microwave test equipment
- 3. Reduce the risk of expensive test equipment damage, repair costs and downtime
- 4. Understand how to correctly perform common RF and microwave measurements
- 5. Understand the basics of low-temperature measurements including critical parameters for superconductors and Josephson junctions, as well as characterization of low-temperature electronic elements
- 6. Better utilize test and measurement equipment features and functionality
- 7. Develop improved problem solving capability due to better understanding

PHGN535. INTERDISCIPLINARY SILICON PROCESSING LABORATORY. 3.0 Semester Hrs.

Equivalent with CBEN435,CBEN535,CHEN435,CHEN535,MLGN535,PHGN435,

(II) Explores the application of science and engineering principles to the fabrication and testing of microelectronic devices with emphasis on specific unit operations and interrelation among processing steps. Teams work together to fabricate, test, and optimize simple devices. Prerequisite: none. 1 hour lecture, 4 hours lab; 3 semester hours.

PHGN542. SOLID STATE DEVICES AND PHOTOVOLTAIC APPLICATIONS. 3.0 Semester Hrs.

(II) An overview of the physical principles involved in the characterization, and operation of solid state devices. Topics will include: semiconductor physics, electronic transport, recombination and generation, intrinsic and extrinsic semiconductors, electrical contacts, p-n junction devices (e.g., LEDs, solar cells, lasers, particle detectors); other semiconductor devices (e.g., bipolar junction transistors and field effect transistors and capacitors). There will be emphasis on optical interactions and application to photovoltaic devices. Prerequisite: PHGN440 or equivalent. 3 hours lecture; 3 semester hours.

PHGN545. QUANTUM MANY-BODY PHYSICS. 3.0 Semester Hrs.

This course offers an introduction to quantum many-body physics in a modern approach from the perspectives of quantum information science. Starting from the difference between classical and quantum correlations, this course introduces composite quantum systems and the concept of entanglement as the central theme in quantum many-body physics. A system of many spin-1/2s is then presented as the paradigmatic quantum many-body system, opening the realm of quantum phase transitions and quantum simulation experiments. Next, systems of non-interacting bosons or fermions are examined using the powerful canonical transformation. To understand what happens when particles interact, the well-known Hubbard model is brought in, together with its importance in quantum materials. Finally, topological ordered quantum matter is introduced and explained via the structure of quantum entanglement. The application of topological order to quantum computing will also be mentioned.

Course Learning Outcomes

- In this course, students will learn to: 1. Describe quantum systems of many individual degrees of freedom.
- 2. Comprehend the concept of quantum entanglement and quantum correlations.
- 3. Analyze quantum phases and phase transitions of a typical quantum many-body model, such as a transverse-field Ising model.
- 4. Solve the energy spectrum of non-interacting fermions and bosons.
- 5. Investigate the qualitative effects of typical interactions among particles.
- 6. Become familiar with quantum simulation experiments.
- 7. Understand topological order of quantum matter and its relation to quantum computing.

PHGN550. NANOSCALE PHYSICS AND TECHNOLOGY. 3.0 Semester Hrs.

An introduction to the basic physics concepts involved in nanoscale phenomena, processing methods resulting in engineered nanostructures, and the design and operation of novel structures and devices which take advantage of nanoscale effects. Students will become familiar with interdisciplinary aspects of nanotechnology, as well as with current nanoscience developments described in the literature. Prerequisites: PHGN320, PHGN341, co-requisite: PHGN462. 3 hours lecture; 3 semester hours.

PHGN566. MODERN OPTICAL ENGINEERING. 3.0 Semester Hrs.

Provides students with a comprehensive working knowledge of optical system design that is sufficient to address optical problems found in their respective disciplines. Topics include paraxial optics, imaging, aberration analysis, use of commercial ray tracing and optimazation, diffraction, linear systems and optical transfer functions, detectors, and optical system examples. 3 hours lecture; 3 semester hours.

PHGN570. FOURIER AND PHYSICAL OPTICS. 3.0 Semester Hrs.

This course addresses the propagation of light through optical systems. Diffraction theory is developed to show how 2D Fourier transforms and linear systems theory can be applied to imaging systems. Analytic and numerical Fourier and microscopes, spectrometers and holographic imaging. They are also applied to temporal propagation in ultrafast optics. Prerequisite: PHGN462 or equivalent. 3 hours lecture; 3 semester hours.

PHGN581. LASER PHYSICS. 3.0 Semester Hrs.

Theory, modeling, and experimental work with: absorption and emission of light from atoms, Gaussian beams, optical resonator theory and design, laser oscillation and pulsing dynamics, introduction to nonlinear optics and ultrafast pulses. Full scope of PHGN480 with more advanced homework, experimental analysis/modeling, and final project.

Course Learning Outcomes

- Be able to explain the interaction of light and quantum transitions, including the origin of gain in different media
- Be able to derive and solve rate equations to describe the balance of stored energy in the gain medium and in the circulating light field in the resonator
- Be able to use matrix methods to calculate the propagation of light as rays and as Gaussian beams and how to use these matrices to design optical resonators

- Build and apply a quantitative model of laser oscillation to a real laser system
- Be able to experimentally align and characterize simple lasers and use advanced diagnostic techniques and analyzis
- Be able to use the techniques developed in the course to analyze a published laser system design

PHGN585. NONLINEAR OPTICS. 3.0 Semester Hrs.
An exploration of the nonlinear response of a medium (semiclassical and quantum descriptions) and nonlinear wave mixing and propagation. Analytic and numeric techniques to treat nonlinear dynamics are developed. Applications to devices and modern research areas are discussed, including harmonic and parametric wave modulation, phase conjugation, electro-optic modulation. Prerequisite: PHGN462 or equivalent, PHGN520. 3 hours lecture; 3 semester hours.

PHGN590. NUCLEAR REACTOR PHYSICS. 3.0 Semester Hrs.
Bridges the gap between courses in fundamental nuclear physics and the practice of electrical power production using nuclear reactors. Review of nuclear constituents, forces, structure, energetics, decay and reactions; interaction of radiation with matter, detection of radiation; nuclear cross sections, neutron induced reactions including scattering, absorption, and fission; neutron diffusion, multiplication, criticality; simple reactor geometries and compositions; nuclear reactor kinetics and control; modeling and simulation of reactors. Prerequisite: PHGN422.

PHGN598. SPECIAL TOPICS. 6.0 Semester Hrs.
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

PHGN599. INDEPENDENT STUDY. 0.5-6 Semester Hr.
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: Independent Study form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

PHGN601. ADVANCED GRADUATE SEMINAR. 1.0 Semester Hr.
(I) Ph.D. students will attend the weekly Physics Colloquium. Students will be responsible for presentations during this weekly seminar. See additional course registration instructions under Program Requirements above. 1 hour seminar; 1 semester hour.

PHGN602. ADVANCED GRADUATE SEMINAR. 1.0 Semester Hr.
(II) Ph.D. students will attend the weekly Physics Colloquium. Students will be responsible for presentations during this weekly seminar. See additional course registration instructions under Program Requirements above. 1 hour seminar; 1 semester hour.

PHGN608. ELECTROMAGNETIC THEORY II. 3.0 Semester Hrs.
Spherical, cylindrical, and guided waves; relativistic 4-dimensional formulation of electromagnetic theory. Prerequisite: PHGN507. 3 hours lecture; 3 semester hours. Offered on demand.

PHGN612. MATHEMATICAL PHYSICS II. 3.0 Semester Hrs.
Continuation of PHGN511. Prerequisite: none. 3 hours lecture; 3 semester hours. Offered on demand.

PHGN623. NUCLEAR STRUCTURE AND REACTIONS. 3.0 Semester Hrs.
The fundamental physics principles and quantum mechanical models and methods underlying nuclear structure, transitions, and scattering reactions. Prerequisite: PHGN521. 3 hours lecture; 3 semester hours. Offered on demand.

PHGN624. NUCLEAR ASTROPHYSICS. 3.0 Semester Hrs.
The physical principles and research methods used to understand nucleosynthesis and energy generation in the universe. Prerequisite: none. 3 hours lecture; 3 semester hours. Offered on demand.

PHGN641. ADVANCED CONDENSED MATTER PHYSICS. 3.0 Semester Hrs.
Provides working graduate-level knowledge of applications of solid state physics and important models to crystalline and non-crystalline systems in two and three dimensions. Review of transport by Bloch electrons; computation, interpretation of band structures. Interacting electron gas and overview of density functional theory. Quantum theory of optical properties of condensed systems; Kramers-Kronig analysis, sum rules, spectroscopies. Response and correlation functions. Theoretical models for metal-insulator and localization transitions in 1, 2, 3 dimensions (e.g., Mott, Hubbard, Anderson, Peierls distortion). Boltzmann equation. Introduction to magnetism; spin waves. Phenomenology of soft condensed matter: order parameters, free energies. Conventional superconductivity. Prerequisites: PHGN440 or equivalent, PHGN520, PHGN530. 3 hours lecture; 3 semester hours.

PHGN698. SPECIAL TOPICS. 6.0 Semester Hrs.
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

PHGN699. INDEPENDENT STUDY. 0.5-6 Semester Hr.
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: Independent Study form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/experience and maximums vary by department. Contact the Department for credit limits toward the degree.

PHGN707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.
(I, II, S) Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.