Physics

Program Description - Engineering Physics

Physics provides the foundation for most applied science and engineering disciplines. It attracts those who wish to understand nature at its most fundamental level. The engineering physics program at Mines (https://physics.mines.edu) is interdisciplinary in nature, taking basic undergraduate physics subjects further with direct applications to engineering. ABET, the Accreditation Board for Engineering and Technology (http://www.abet.org), accredits the degree to provide graduates the first step towards professional licensure.

At Mines, the required engineering physics curriculum includes the requisite undergraduate physics courses that form rigorous study at any 4-year university. In addition to these core courses, Mines requirements include pre-engineering and engineering classes that physics majors at other universities would not ordinarily take. These courses include immersions in engineering science, engineering design, systems, a summer field session practicum, and a capstone senior design sequence culminating in a senior thesis.

The unique blend of physics and engineering makes it possible for a Mines engineering physics graduate to work at the interface between science and technology where new discoveries are made and continually being put into practice. While engineering physicists are proficient applying existing technologies, they are also willing to explore novel approaches and capable of developing new technologies. The excitement and fulfillment of working on innovative challenges make a Mines engineering physics degree attractive to many students.

With the flexibility of our degree, our undergraduates find themselves following a variety of career paths. Many find employment in fields as diverse as aerospace engineering, biomedical science, computational modeling of physical systems, device manufacturing and semiconductor processing, geophysics, materials development, nanotechnology, nuclear science and engineering, renewable and conventional energy industries, semiconductor manufacturing and processing, energy, and even entertainment enterprises that place high demands on animation, audio, special effects, and visualization talents. More than half of our seniors pursue graduate studies in physics or a closely related field of engineering. Some take their undergraduate training into post-graduate professional studies in business, law, management, medicine, or quantum engineering.

Mines physics faculty and staff maintain modern, state-of-the-art laboratories for general physics, modern physics, electronics, and advanced investigations. There are research laboratories for the study of condensed matter, materials science, nuclear physics, optics, and quantum physics & computing. The department maintains well-equipped, professionally staffed, electronic labs and machine shops to help students and faculty accomplish their curriculum, project, and research goals. The department also nurtures strong ties with national laboratories and local engineering design firms that provide students with authentic collaboration opportunities.

Program Educational Objectives (Bachelor of Science in Engineering Physics)

In addition to contributing toward achieving the educational objectives described in the CSM Graduate Profile, the Physics Department is dedicated to additional educational objectives.

The program prepares graduates who, based on factual knowledge and other skills necessary to construct an appropriate understanding of physical phenomena in applied contexts, will:

1. Obtain a range of positions in industry or positions in government facilities or pursue graduate education in engineering, science or related fields;
2. Communicate and perform effectively within the criteria of their chosen careers;
3. Engage in appropriate professional societies and continuing education activities;
4. Participate ethically as members of the global society.

Student Learning Outcomes

1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
2. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
3. An ability to communicate effectively with a range of audiences.
4. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, and meet objectives.
5. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
6. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Degree Requirements (Engineering Physics)

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<thead>
<tr>
<th>Freshman</th>
<th>Fall</th>
<th>lec</th>
<th>lab</th>
<th>sem.hrs</th>
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<td>CSCI128</td>
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16.0
EBGN321 ENGINEERING ECONOMICS 3.0

*For the 2023 Catalog
EBGN321 replaced EBGN201 as a Core requirement. EBGN321 was added to the core, but has a prerequisite of 60 credit hours. Students whose programs that required EBGN201 the sophomore year may need to wait to take EBGN321 until their junior year. For complete details, please visit: https://www.mines.edu/registrar/core-curriculum/

Senior

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<td>PHGN462</td>
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Spring

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<td>FREE</td>
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Total Semester Hrs: 130.0

Major GPA

During the 2016-2017 Academic Year, the Undergraduate Council considered the policy concerning required major GPAs and which courses are included in each degree’s GPA. While the GPA policy has not been officially updated, in order to provide transparency, council members agreed that publishing the courses included in each degree’s GPA is beneficial to students.

The following list details the courses that are included in the GPA for this degree:

PHGN100 through PHGN599 inclusive

Combined Baccalaureate/Masters and Baccalaureate/Doctoral Degree Programs

The Physics Department offers combined BS/MS degree programs in which students obtain an undergraduate degree in Engineering Physics, in as few as four years, as well as a masters degree in Applied Physics,
in an Engineering discipline, in Technology Management, in Materials Science, or in Mathematics, after an additional year of study. There are engineering tracks, physics tracks, a management track, a materials science track, and a mathematics track. These programs emphasize a strong background in fundamentals of science, in addition to practical experience within an applied science, engineering, or mathematics discipline. Many of the undergraduate electives of students involved in each track are specified. For this reason, students are expected to apply to the program during the first semester of their sophomore year (in special cases late entry can be approved by the program mentors). A 3.0 grade point average must be maintained to guarantee admission into the physics, engineering, and mathematics science graduate programs. A 3.3 grade point average must be maintained to guarantee admission into the mathematics graduate program.

Students in the engineering tracks must complete a report or case study during the last year. Students in the physics, materials science, and mathematics tracks must complete a master's thesis. Students in the nuclear engineering program can choose between thesis and non-thesis options. The case study or thesis should begin during the senior year as part of the Senior Design experience. Participants must identify an engineering or physics advisor as appropriate prior to their senior year who will assist in choosing an appropriate project and help coordinate the senior design project with the case study or thesis completed in the last year.

It is also possible for undergraduate students to begin work on a doctoral degree in Applied Physics while completing the requirements for their bachelor's degree. Students in this combined baccalaureate/doctoral program may fulfill part of the requirements of their doctoral degree by including up to six hours of specified course credits that are also used to fulfill the requirements of their undergraduate degree. These courses may only be applied toward fulfilling doctoral degree requirements. Courses must meet all requirements for graduate credit, but their grades are not included in calculating the graduate GPA.

Interested students can obtain additional information and detailed curricula from the Physics Department or from the participating engineering departments.

The Mines guidelines for Minor/ASI can be found in the Undergraduate Information section of the Mines Catalog.

### Minor in Engineering Physics

#### Required Courses - 7.0 credits

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credit Hours</th>
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<tbody>
<tr>
<td>PHGN200</td>
<td>PHYSICS II-ELECTROMAGNETISM AND OPTICS</td>
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<tr>
<td>PHGN300</td>
<td>PHYSICS III-MODERN PHYSICS I</td>
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<td>or PHGN310</td>
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#### Elective Courses (select at least 11 credits from the following)

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<td>PHGN215</td>
<td>ANALOG ELECTRONICS</td>
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<td>PHGN315</td>
<td>ADVANCED PHYSICS LAB I</td>
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<tr>
<td>PHGN317</td>
<td>SEMICONDUCTOR CIRCUITS- DIGITAL</td>
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<tr>
<td>PHGN324</td>
<td>INTRODUCTION TO ASTRONOMY AND ASTROPHYSICS</td>
<td>3.0</td>
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<td>PHGN326</td>
<td>ADVANCED PHYSICS LAB II</td>
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<tr>
<td>PHGN384</td>
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<tr>
<td>PHGN399</td>
<td>INDEPENDENT STUDY</td>
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<tr>
<td>PHGN417</td>
<td>FUNDAMENTALS OF QUANTUM INFORMATION</td>
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<td>PHGN419</td>
<td>PRINCIPLES OF SOLAR ENERGY SYSTEMS</td>
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### Minor in Physics

#### Required Courses (16.5 credits)

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<td>PHGN300</td>
<td>PHYSICS III-MODERN PHYSICS I</td>
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<tr>
<td>or PHGN310</td>
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<tr>
<td>MATH332</td>
<td>LINEAR ALGEBRA</td>
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<tr>
<td>CSC1250</td>
<td>PYTHON-BASED COMPUTING: BUILDING A SENSOR SYSTEM</td>
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#### Elective Courses (select at least 2.0 credits from the following)

<table>
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<tr>
<td>PHGN320</td>
<td>MODERN PHYSICS II: BASICS OF QUANTUM MECHANICS</td>
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<td>PHGN341</td>
<td>THERMAL PHYSICS</td>
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<td>PHGN350</td>
<td>INTERMEDIATE MECHANICS</td>
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<td>PHGN361</td>
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<tr>
<td>PHGN450</td>
<td>COMPUTATIONAL PHYSICS</td>
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### Courses

**PHGN100. PHYSICS I - MECHANICS. 4.0 Semester Hrs.**

(I,II,S) 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. Prerequisite: MATH111. Co-requisites: MATH112 or MATH113 or MATH122. 2 hours lecture; 4 hours studio; 4.5 semester hours. Approved for Colorado Guaranteed General Education transfer. Equivalency for GT-SC1.

**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.
PHGN315. ADVANCED PHYSICS LAB I. 2.0 Semester Hrs.
(I) (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. Prerequisite: PHGN300/310, PHGN384. 1 hour lecture, 3 hours lab; 2 semester hours.

PHGN317. SEMICONDUCTOR CIRCUITS- DIGITAL. 3.0 Semester Hrs.
(I) 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 CSC250. 2 hours lecture; 3 hours lab; 3 semester hours.

PHGN320. MODERN PHYSICS II: BASICS OF QUANTUM MECHANICS. 4.0 Semester Hrs.
(II) 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.
(I) 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.

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

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.
(II) 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. Prerequisite: CHGN122 or CHGN125 and PHGN311. 3 hours lecture; 3 semester hours.

PHGN350. INTERMEDIATE MECHANICS. 4.0 Semester Hrs.
(I) 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. Prerequisite: PHGN200. Corequisite: PHGN311. 4 hours lecture; 4 semester hours.
PHGN361. INTERMEDIATE ELECTROMAGNETISM. 3.0 Semester Hrs.
(I) 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. Prerequisite: PHGN200 and PHGN311. 3 hours lecture; 3 semester hours.

PHGN384. FIELD SESSION TECHNIQUES IN PHYSICS. 1-6 Semester Hr.
(S) 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, CSCI250. 6 semester hours.

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 project 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.

PHGN418. GENERAL RELATIVITY. 3.0 Semester Hrs.
(II) 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.

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.

PHGN424. ASTROPHYSICS. 3.0 Semester Hrs.
(II) 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.

PHGN440. PARTICLE PHYSICS. 3.0 Semester Hrs.
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 MATH214 or MATH223 or MATH224.

PHGN444. SOLID STATE PHYSICS. 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 PHGN444.) Prerequisite: PHGN320. 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.

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

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.
(I) (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.
(II) (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.
(I) 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.

PHGN481. SENIOR DESIGN PRACTICE. 2.5 Semester Hrs.
(I) (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.
(II) (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.
(I) (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.
(II) (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 semester hours.

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.

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Reuben T. Collins
Thomas E. Furtak
Frank V. Kowalski
John Scales
P. Craig Taylor
John Trefny, President Emeritus
Don L. Williamson

**Associate Professors Emeriti**
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**Professors**
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