Physics

Program Description - Engineering Physics

Physics is the most basic of all sciences and the foundation of most of the science and engineering disciplines. As such, it has always attracted those who want to understand nature at its most fundamental level. Engineering Physics is not a specialized branch of physics, but an interdisciplinary area wherein the basic physics subject matter, which forms the backbone of any undergraduate physics degree, is taken further toward application to engineering. The degree is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET). At Mines, the required engineering physics curriculum includes all of the undergraduate physics courses that would form the physics curriculum at any good university, but in addition to these basic courses, the Mines requirements include pre-engineering and engineering courses, which physics majors at other universities would not ordinarily take. These courses include engineering science, design, systems, summer field session, and a capstone senior design sequence culminating in a senior thesis.

This unique blend of physics and engineering makes it possible for the engineering physics graduate to work at the interface between science and technology, where new discoveries are continually being put to practice. While the engineering physicist is at home applying existing technologies, he or she is also capable of striking out in different directions to develop new technologies. It is the excitement of being able to work at this cutting edge that makes the engineering physics degree attractive to many students.

Career paths of Mines engineering physics graduates vary widely, illustrating the flexibility inherent in the program. More than half of the graduating seniors go on to graduate school in physics or a closely related field of engineering. Some go to medical, law, or other professional post-graduate schools. Others find employment in fields as diverse as electronics, semiconductor processing, aerospace, materials development, biomedical applications, nuclear energy, solar energy, and geophysical exploration.

The Physics Department maintains modern well-equipped laboratories for general physics, modern physics, electronics, and advanced experimentation. There are research laboratories for the study of condensed matter physics, surface physics, materials science, optics, and nuclear physics, including an NSF-funded laboratory for solar and electronic materials processing. The Department also maintains electronic and machine shops.

The program leading to the degree of Bachelor of Science in Engineering Physics is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.

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.

Degree Requirements (Engineering Physics)

<table>
<thead>
<tr>
<th>Freshman</th>
<th>Fall</th>
<th>lec</th>
<th>labem.hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH111</td>
<td>CALCULUS FOR SCIENTISTS AND ENGINEERS I</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>CHGN121</td>
<td>PRINCIPLES OF CHEMISTRY I</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>HASS100</td>
<td>NATURE AND HUMAN VALUES</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>CSM101</td>
<td>FRESHMAN SUCCESS SEMINAR</td>
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<tr>
<td>GEGN101</td>
<td>EARTH AND ENVIRONMENTAL SYSTEMS, CBEN 110, or CSCI101 and CSCI102 [if student chooses to complete CSCI101 (3 credits) for the Distributed Science requirement, they must also take CSCI102 (1 credit) lab course to meet the 4 total hours required.]</td>
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| Elective | PHYSICAL ACTIVITY COURSE | 0.5 |

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<tr>
<th>Spring</th>
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<tr>
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<tr>
<td>CHGN122</td>
<td>PRINCIPLES OF CHEMISTRY II (SC1) or 125</td>
<td>4.0</td>
</tr>
<tr>
<td>PHGN100</td>
<td>PHYSICS I - MECHANICS</td>
<td>4.5</td>
</tr>
<tr>
<td>EDNS151</td>
<td>DESIGN I</td>
<td>3.0</td>
</tr>
<tr>
<td>PAGN</td>
<td>PHYSICAL ACTIVITY COURSE</td>
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<th>Sophomore</th>
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<tr>
<td>Fall</td>
<td>MATH213</td>
<td>CALCULUS FOR SCIENTISTS AND ENGINEERS III</td>
</tr>
<tr>
<td>PHGN200</td>
<td>PHYSICS II- ELECTROMAGNETISM AND OPTICS</td>
<td>4.5</td>
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<tr>
<td>EDNS269</td>
<td>DESIGN II: ENGINEERING PHYSICS, 251, 261, 262, 263, 264, CEEN 267, or GPGN 268</td>
<td>3.0</td>
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<tr>
<td>HASS200</td>
<td>GLOBAL STUDIES</td>
<td>3.0</td>
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<tr>
<td>PAGN</td>
<td>PHYSICAL ACTIVITY COURSE</td>
<td>0.5</td>
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| Elective | PHYSICAL ACTIVITY COURSE | 0.5 |

<table>
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<tr>
<th>Total</th>
<th>16.0</th>
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| Elective | PHYSICAL ACTIVITY COURSE | 0.5 |

| Total    | 15.0 |
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, independently, and in collaboration with the Department of Applied Mathematics and Statistics, the Department of Mechanical Engineering, the Department of Electrical Engineering and Computer Science, the Materials Science Program, and the Nuclear Science and Engineering Program 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 Materials Science, or in Mathematics, after an additional year of study. There are three engineering tracks, three physics tracks, 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. It is also possible for undergraduate students to begin work on a doctoral degree programs in which students obtain an undergraduate degree in Applied Physics, in an Engineering discipline, in Materials Science, Engineering Physics, in as few as four years, as well as a masters degree in Applied Physics, in an Engineering discipline, in Materials Science, or in Mathematics, after an additional year of study. There are three engineering tracks, three physics tracks, 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. It is also possible for undergraduate students to begin work on a doctoral degree programs in which students obtain an undergraduate degree in Applied Physics, in an Engineering discipline, in Materials Science, Engineering Physics, in as few as four years, as well as a masters degree in Applied Physics, in an Engineering discipline, in Materials Science, or in Mathematics, after an additional year of study. There are three engineering tracks, three physics tracks, 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 materials 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.
General CSM Minor/ASI requirements can be found here (catalog.mines.edu/undergraduate/undergraduateinformation/minorasi).

**Minor and Area of Special Interest**

The department offers a Minor and Area of Special Interest for students not majoring in physics. The requirements are as follows:

**Area of Special Interest (12 semester hours minimum)**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Hours</th>
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<tbody>
<tr>
<td>PHGN100</td>
<td>PHYSICS I - MECHANICS</td>
<td>4.5</td>
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<tr>
<td>or PHGN200</td>
<td>PHYSICS II-ELECTROMAGNETISM AND OPTICS</td>
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**Minor (18 semester hours minimum)**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Hours</th>
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<tbody>
<tr>
<td>PHGN100</td>
<td>PHYSICS I - MECHANICS</td>
<td>4.5</td>
</tr>
<tr>
<td>or PHGN200</td>
<td>PHYSICS II-ELECTROMAGNETISM AND OPTICS</td>
<td></td>
</tr>
<tr>
<td>PHGN300</td>
<td>PHYSICS III-MODERN PHYSICS I</td>
<td>3.0</td>
</tr>
<tr>
<td>or PHGN310</td>
<td>HONORS PHYSICS III-MODERN PHYSICS</td>
<td></td>
</tr>
<tr>
<td>PHGN320</td>
<td>MODERN PHYSICS II: BASICS OF QUANTUM MECHANICS</td>
<td>4.0</td>
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Select one of the following: 3-4

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Hours</th>
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<tbody>
<tr>
<td>PHGN341</td>
<td>THERMAL PHYSICS</td>
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</tr>
<tr>
<td>PHGN350</td>
<td>INTERMEDIATE MECHANICS</td>
<td></td>
</tr>
<tr>
<td>PHGN361</td>
<td>INTERMEDIATE ELECTROMAGNETISM</td>
<td></td>
</tr>
</tbody>
</table>

Selected courses to complete the Minor: Upper division (400-level) and/or graduate (500-level) courses which form a logical sequence in a specific field of study as determined in consultation with the Physics Department and the student’s option department.

**Biophysics Minor**

To obtain a Biophysics Minor, students must take at least 18.0 credits related to Biophysics. Two courses (8.0 credits) of Biology are required. Two additional requirements include Biophysics (PHGN433) and Laser Physics (PHGN480). Two more courses (or at least 4.0 credits) may be chosen from the list below. The list of electives will be modified as new related courses that fall into these categories become available. While the current emphasis of the Biophysics Minor is on optical techniques, we intend to add alternative tracks, for example radiologic (nuclear) techniques.

**Required Courses (14.0 Credits)**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Hours</th>
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<tbody>
<tr>
<td>CBEN110</td>
<td>FUNDAMENTALS OF BIOLOGY I</td>
<td>4.0</td>
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<tr>
<td>CBEN120</td>
<td>FUNDAMENTALS OF BIOLOGY II</td>
<td>4.0</td>
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<tr>
<td>PHGN433</td>
<td>BIOPHYSICS</td>
<td>3.0</td>
</tr>
<tr>
<td>PHGN480</td>
<td>LASER PHYSICS</td>
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**Two Elective courses (at least 4.0 credits) from the list below:**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Hours</th>
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<tbody>
<tr>
<td>PHGN466</td>
<td>MODERN OPTICAL ENGINEERING</td>
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<tr>
<td>or PHGN566</td>
<td>MODERN OPTICAL ENGINEERING</td>
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<tr>
<td>PHGN570</td>
<td>FOURIER AND PHYSICAL OPTICS</td>
<td>3.0</td>
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<tr>
<td>CBEN310</td>
<td>INTRODUCTION TO BIOMEDICAL ENGINEERING</td>
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<tr>
<td>CBEN311</td>
<td>INTRODUCTION TO NEUROSCIENCE</td>
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</tr>
<tr>
<td>CBEN431</td>
<td>IMMUNOLOGY FOR ENGINEERS AND SCIENTISTS</td>
<td>3.0</td>
</tr>
<tr>
<td>or CBEN531</td>
<td>IMMUNOLOGY FOR SCIENTISTS AND ENGINEERS</td>
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<tr>
<td>CBEN454</td>
<td>APPLIED BIOINFORMATICS</td>
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</table>
Teaching Assistant Professor
Emily M. Smith

Research Professor
Mark W. Coffey

Research Associate Professor
Wendy Adams Spencer

Research Assistant Professors
Daniel Adams
P. David Flammer
Prashun Gorai
Laith Haddad
Lakshmi Krishna
Lokender Kumar
Nitin Kumar
Gavriil Shchedrin
K. Xerxes Steirer

Professors Emeriti
F. Edward Cecil
Thomas E. Furtak
Frank V. Kowalski
John Scales
P. Craig Taylor
John Trefny, President Emeritus
Don L. Williamson

Associate Professors Emeriti
David M. Wood

Courses
ENGY200. INTRODUCTION TO ENERGY. 3.0 Semester Hrs.
Introduction to Energy. Survey of human-produced energy technologies including steam, hydro, fossil (petroleum, coal, and unconventional), geothermal, wind, solar, biofuels, nuclear, and fuel cells. Current and possible future energy transmission and efficiency. Evaluation of different energy sources in terms of a feasibility matrix of technical, economic, environmental, and political aspects. 3 hours lecture; 3 semester hours.

ENGY310. INTRO TO FOSSIL ENERGY. 3.0 Semester Hrs.
(ii) Students will learn about conventional coal, oil, and gas energy sources across the full course of exploitation, from their geologic origin, through discovery, extraction, processing, marketing, and finally to their end-use in society. Students will be introduced to the key technical concepts of flow through rock, the geothermal temperature and pressure gradients, hydrodynamics, and structural dynamics as needed to understand the key technical challenges of mining, drilling, and production. Students will then be introduced to unconventional (emerging) fossil-based resources, noting the key drivers and hurdles associated with their development. Students will learn to quantify the societal cost and benefits of each fossil resource across the full course of exploitation and in a final project will propose or evaluate a national or global fossil energy strategy, supporting their arguments with quantitative technical analysis. 3 hours lecture; 3 semester hours.

ENGY320. INTRO TO RENEWABLE ENERGY. 3.0 Semester Hrs.
(i) Survey of renewable sources of energy. The basic science behind renewable forms of energy production, technologies for renewable energy storage, distribution, and utilization, production of alternative fuels, intermittency, natural resource utilization, efficiency and cost analysis and environmental impact. 3 hours lecture; 3 semester hours.

ENGY330. ENERGY ECONOMICS. 3.0 Semester Hrs.
Equivalent with EBGN330,
(i). Study of economic theories of optimal resource extraction, market power, market failure, regulation, deregulation, technological change and resource scarcity. Economic tools used to analyze OPEC energy mergers, natural gas price controls and deregulation, electric utility restructuring, energy taxes, environmental impacts of energy use, government R&D programs, and other energy topics. Prerequisites: EBGN201 or EBGN311. 3 hours lecture; 3 semester hours.

ENGY340. NUCLEAR ENERGY. 3.0 Semester Hrs.
(i) Survey of nuclear energy and the nuclear fuel cycle including the basic principles of nuclear fission and an introduction to basic nuclear reactor design and operation. Nuclear fuel, uranium resources, distribution, and fuel fabrication, conversion and breeding. Nuclear safety, nuclear waste, nuclear weapons and proliferation as well economic, environmental and political impacts of nuclear energy. 3 hours lecture; 3 semester hours.

ENGY350. GEOTHERMAL ENERGY. 3.0 Semester Hrs.
(i) Geothermal energy resources and their utilization, based on geoscience and engineering perspectives. Geoscience topics include world wide occurrences of resources and their classification, heat and mass transfer, geothermal reservoirs, hydrothermal geochemistry, exploration methods, and resource assessment. Engineering topics include thermodynamics of water, power cycles, electricity generation, drilling and well measurements, reservoir-surface engineering, and direct utilization. Economic and environmental considerations and case studies are also presented. 3 hours lecture; 3 semester hours.

ENGY390. ENERGY AND SOCIETY. 3.0 Semester Hrs.
Equivalent with LAIS490, MNGN490,
(ii). A transdisciplinary capstone seminar that explores a spectrum of approaches to the understanding, planning, and implementation of energy production and use, including those typical of diverse private and public (national and international) corporations, organizations, states, and agencies. Aspects of global energy policy that may be considered include the historical, social, cultural, economic, ethical, political, and environmental aspects of energy together with comparative methodologies and assessments of diverse forms of energy development. Prerequisites: ENGY330/EBGN330 and one of either ENGY310, ENGY320, or ENGY340. 3 hours lecture/seminar; 3 semester hours.
PHGN100. PHYSICS I - MECHANICS. 4.5 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.

PHGN200. PHYSICS II-ELECTROMAGNETISM AND OPTICS. 4.5 Semester Hrs.  
(I, II, S) 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, concurrent enrollment in MATH213 or MATH214 or MATH223. 2 hours lecture; 4 hours studio; 4.5 semester hours.

PHGN215. ANALOG ELECTRONICS. 4.0 Semester Hrs.  
(II) 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. Prerequisite: PHGN200. 3 hours lecture, 3 hours lab; 4 semester hours.

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.  
(I) 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. Prerequisite: PHGN200; Concurrent enrollment in MATH225. 3 hours lecture; 3 semester hours.

PHGN310. HONORS PHYSICS III-MODERN PHYSICS. 3.0 Semester Hrs.  
Equivalent with PHGN300.  
(II) 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. Prerequisite: PHGN200; Concurrent enrollment in MATH225. 3 hours lecture; 3 semester hours.

PHGN311. INTRODUCTION TO MATHEMATICAL PHYSICS. 3.0 Semester Hrs.  
(I) 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. Prerequisites: PHGN300 or PHGN310, MATH225, MATH332, and CSCi250. 3 hours lecture; 3 semester hours.

PHGN315. ADVANCED PHYSICS LAB I. 1.0 Semester Hrs.  
(I) (II) 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 CSCi250. 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 spectrums, angular momentum, perturbation theory, and the treatment of identical particles. Example applications taken from atomic, molecular, solid state or nuclear systems. Prerequisites: PHGN300 or PHGN310 and PHGN311. 4 hours lecture; 4 semester hours.

PHGN324. INTRODUCTION TO ASTRONOMY AND ASTROPHYSICS. 3.0 Semester Hrs.  
(II) 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. Prerequisite: PHGN200. 3 hours lecture; 3 semester hours.

PHGN326. ADVANCED PHYSICS LAB II. 2.0 Semester Hrs.  
(II) (WI) 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.
(I) 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.
(II) 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, PHGN215, 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 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. THEORETICAL PHYSICS SEMINAR. 1.0 Semester Hr.
(I, II) Students will attend the weekly theoretical physics seminar. Students will be responsible for presentation and discussion. Corequisite: PHGN300/PHGN310. 1 hour lecture; 1 semester hour.

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.
(II) 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. Corequisites: PHGN320. 3 hour lecture.

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 BELS333, PHGN333.
(II) 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.

PHGN435. INTERDISCIPLINARY MICROELECTRONICS PROCESSING LABORATORY. 3.0 Semester Hrs.
Equivalent with CBEN435, CBEN335, CHEN335, CHEN335, MLGN335, PHGN335, 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. Prerequisites: Senior standing in PHGN, CHGN, MTGN, or EGGN. 1.5 hours lecture, 4 hours lab; 3 semester hours.

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. (Graduate students in physics may register only for PHGN440.) Prerequisite: PHGN320. 3 hours lecture; 3 semester hours.
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.

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. Prerequisite: PHGN462. 3 hours lecture; 3 semester hours.

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.

PHGN499. 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.