Physics

Degrees Offered

- Master of Science (Applied Physics)
- Master of Science Non-Thesis (Applied Physics)
- Doctor of Philosophy (Physics)
- Graduate Certificate (Optics for Engineering)

Program Description

The Physics Department at Mines offers a full program of instruction and research leading to the MS in Applied Physics or PhD in Physics. It also contributes to graduate interdisciplinary programs in Materials Science (MS and PhD), Nuclear Engineering (MS and PhD), and Quantum Engineering (MS). The research in these graduate programs is supported by external grants and contracts totaling $6.37M/year in research expenditures. Research in the department is organized under three primary themes: subatomic physics, condensed matter physics, and applied optics. With 23 faculty, 66 graduate students, and 225 undergraduate physics majors, the Physics Department at Mines is a vibrant intellectual community providing high-quality education in state-of-the-art facilities.

Graduate students are given a solid background in the fundamentals of classical and modern physics at an advanced level and are encouraged early in their studies to learn about the research interests of the faculty so that a thesis topic can be identified.

Program Requirements

Students entering graduate programs in the Physics Department will select an initial program in consultation with the departmental graduate student advising committee until such time as a research field has been chosen and a thesis committee appointed.

Master of Science

Requirements:

MS-Thesis in Applied Physics: 18 credits of course work in an approved program, 2 credits of seminar, plus 10 credits of research credit, with a satisfactory thesis.

MS-non-Thesis in Applied Physics: 28 credits of course work and 2 credits of seminar. At least 21 of the required 30 credits of course work must be taken as a registered master's degree student at Mines. The program will allow up to 7 credits of independent study coursework to count towards the non-thesis MS degree. Up to 9 credits of graduate courses may be transferred into the degree program, provided that those courses have not been used as credit toward a Bachelor's degree. The student's committee makes decisions on courses to be taken, transfer credit, and examines the student's written report and oral presentation resulting from an independent study.

Mines' Combined Undergraduate/Graduate Degree Program

Students enrolled in Mines' combined undergraduate/graduate program may double count up to 6 credits of graduate coursework to fulfill requirements of both their undergraduate and graduate degree programs. These courses must have been passed with B- or better, not be substitutes for required coursework, and meet all other university, department, and program requirements for graduate credit.

Students are advised to consult with their undergraduate and graduate advisors for appropriate courses to double count upon admission to the combined program.

Doctor of Philosophy

Requirements: 32 credits of coursework in an approved program plus 40 credits of research credit, with a satisfactory thesis. 12 credits of course work will be in a specialty topic area defined in consultation with the thesis advisor. Possible specialty topic areas within the Physics Department exist in Optical Science and Engineering, Condensed Matter Physics, Theoretical Physics, Renewable Energy Physics, and Nuclear/Particle Physics and Astrophysics.

To demonstrate adequate preparation for the PhD degree in Physics, each student must achieve a grade point average of 3.0 or better in the core courses. Students not meeting this standard must pass oral examinations covering the relevant course content or retake the courses within one year. This process is part of the requirement for admission to candidacy, which full time PhD students must complete within two calendar years of admission, as described in the campus-wide graduate degree requirements section of this bulletin. Other degree requirements, time limits, and procedural details can be found in the Physics Department Graduate Student Advising Brochure.

Physics Colloquium

All full-time physics graduate students must attend the Physics Colloquium, which is represented in the curriculum by the Graduate Seminar courses. Students must take one of these courses every semester that they are enrolled at Mines. Those students who are in the MS Program, sign up for PHGN501 (fall) and PHGN502 (spring). Students in the PhD program sign up for PHGN601 (fall) and PHGN602 (spring). At the end of each semester students are assigned either a satisfactory or unsatisfactory progress grade, based on attendance, until the final semester of the student's degree program, when a letter grade is assigned based on all prior semesters' attendance grades. As a result, while these courses are taken each year, only 1 hour total of course credit is conferred for each of 501, 502, 601, or 602. Students who have official part-time status and who have already taken at least one semester of 501 and 502 for the MS degree, or 601 and 602 for the PhD degree are not required to sign up for Graduate Seminar during subsequent semesters.

Prerequisites

The Graduate School of Colorado School of Mines is open to graduates from four-year programs at accredited colleges or universities. Admission to the Physics Department MS and PhD programs is competitive and is based on an evaluation of undergraduate performance, standardized test scores, and references. The undergraduate course of study of each applicant is evaluated according to the requirements of the Physics Department.

Required Curriculum

Master of Science (with Thesis) in Applied Physics

Core Courses		
PHGN511	MATHEMATICAL PHYSICS	3.0

PHGN515	GRADUATE LABORATORY	3.0
PHGN520	QUANTUM MECHANICS I	3.0
PH ELECT	Electives **	9.0
PHGN501 & PHGN502	GRADUATE SEMINAR and GRADUATE SEMINAR *	2.0
PHGN707	GRADUATE THESIS / DISSERTATION RESEARCH CREDIT	10.0
Total Semester Hrs		**30.0**

* Graduate Seminar: Each full-time MS graduate student will register for Graduate Seminar each semester for a total of 2 cumulative credits over the degree.

** Electives maybe chosen from classes taught in physics or relevant classes taught in other departments, as approved by the graduate advisor and thesis committee.

Master of Science (non-Thesis) in Applied Physics

Core Courses		
PHGN511	MATHEMATICAL PHYSICS	3.0
PHGN515	GRADUATE LABORATORY	3.0
PH ELECT	Electives **	22.0
PHGN501 & PHGN502	GRADUATE SEMINAR and GRADUATE SEMINAR *	2.0
Total Semester Hrs		**30.0**

* Graduate Seminar: Each full-time MS graduate student will register for Graduate Seminar each semester for a total of 2 cumulative credits over the degree.

** Electives may be chosen from additional classes in physics, other disciplines relevant to their focus, and one of CSM 501 (Grad Student Skills), SYGN 501 (research skills for graduate students), or responsible conduct of research (PHGN 503 or SYGN 502).
At least one elective must be in a course with a significant laboratory or design emphasis. Courses with a laboratory component include, PHGN 532 Low Temp Microwave measurement, PHGN 535 Microprocessing lab, and PHGN 581 laser physics. Coursework with heavily applied components include, MLGN502 Solid State Physics, PHGN 504 Radiation Detection, PHGN 519 Fundamentals of Quantum Information, PHGN 542 Solid State Devices, PHGN 566 Modern optical Engineering. Other classes that fulfil this requirement may be approved by the graduate advisor.
The program will allow up to 7 credits of independent study coursework to count towards the non-thesis MS degree.

Doctor of Philosophy in Physics

Core Courses		
PHGN507	ELECTROMAGNETIC THEORY I	3.0
PHGN511	MATHEMATICAL PHYSICS	3.0
PHGN515	GRADUATE LABORATORY	3.0
PHGN520	QUANTUM MECHANICS I	3.0
PHGN521	QUANTUM MECHANICS II	3.0
PHGN530	STATISTICAL MECHANICS	3.0
PHGN601 & PHGN602	ADVANCED GRADUATE SEMINAR and ADVANCED GRADUATE SEMINAR *	2.0
PH ELECT	Special topic area electives	12.0
PHGN707	GRADUATE THESIS / DISSERTATION RESEARCH CREDIT	40.0
Total Semester Hrs		**72.0**

* Graduate Seminar: Each full-time PhD graduate student will register for Graduate Seminar each semester for a total of 2 cumulative credits over the degree.

Fields of Research

Applied Optics and Biophysics: lasers, ultrafast optics, non-linear optics, laser-produced plasmas, micromachining, multiphoton microscopy, single-molecule microscopy, total internal reflection microscopy, biophysical mechanisms of collagen fibril degradation, novel imaging techniques.

Subatomic: low energy nuclear structure and astrophysics, applied nuclear physics, high-energy cosmic-ray and neutrino physics, neutrinoless double beta decay,

Condensed Matter and Materials Physics: photovoltaics, thermoelectrics, plasmonics, materials discovery, thin-film semiconductors, amorphous materials, excitonic materials, optoelectronic materials, nanostructures and quantum dots, self-assembled systems, organic and soft condensed matter, x-ray diffraction, Raman spectroscopy, x-ray photoelectron spectroscopy, Auger spectroscopy, scanning probe microscopies, atom probe tomography, first principles condensed materials theory**,** electronic structure, topological disorder.

Quantum Physics: quantum chaos, strongly-correlated states, quantum computing, quantum information, quantum simulation, quantum many-body theory, quantum error correction, disorder in quantum materials, applied superconductivity, low-temperature physics, spintronics.

GRADUATE CERTIFICATE IN OPTICS FOR ENGINEERING

Program Requirements

The graduate certificate program in Optics for Engineering is targeted to train recent graduates or midcareer professionals with a Bachelor of Science degree in physics, chemistry, materials science, electrical or mechanical engineering, or other related fields. The program will provide them with a basic knowledge of optics and lasers so they can apply it to the challenges and demands of advanced technologies that use optical systems. the program offers students a number of electives to choose from and to tailor their education to their interest.

Graduate Certificate Curriculum Requirements:

The certificate option consists of one core class, plus two additional electives, for a total of 9 credit hours. PHGN461 is considered a prerequisite for this certificate but is offered online in the summer, allowing students to easily fulfill this requirement. Students who have taken the equivalent of PHGN461 at a different institution can request to have this prerequisite waived.

Graduate Certificate

PHGN581	LASER PHYSICS	3.0
Electives	See Elective Listing	6.0

Coursework Details:

Students will need PHGN461 (or its equivalent) as a prerequisite for the certificate. This course is offered in the summer (online). PHGN581 is offered in the fall (in-person). Students will select two electives from the approved list below.

Approved Electives (select two):

PHGN570	FOURIER AND PHYSICAL OPTICS	3.0
PHGN566	MODERN OPTICAL ENGINEERING	3.0
PHGN585	NONLINEAR OPTICS	3.0
EENG528	COMPUTATIONAL ELECTROMAGNETICS	
GPGN570	APPLICATIONS OF SATELLITE REMOTE SENSING	3.0
EENG507	INTRODUCTION TO COMPUTER VISION	3.0
EENG509	SPARSE SIGNAL PROCESSING	3.0
EENG515	MATHEMATICAL METHODS FOR SIGNALS AND SYSTEMS	3.0

Courses

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.

PHGN526. QUANTUM ENGINEERING SEMINAR (FALL). 1.0 Semester Hr.
The Quantum Engineering Seminar Series offers graduate students an opportunity to engage with leading professionals from the quantum industry. Through a series of guest lectures, students will explore cutting-edge developments in quantum technology, including quantum computing, sensing, materials, and communications. The course emphasizes professional development by fostering networking skills, enhancing career readiness, and encouraging interdisciplinary collaboration. Students will be encouraged to develop a ‘portfolio’ with summaries of discussions, follow up correspondence with speakers, and reflections on how they see their future careers in this field. This seminar series aligns with the Mines@150 mission, preparing students to become innovative leaders in the evolving field of quantum engineering.
Course Learning Outcomes

- Students will gain an understanding of current trends, challenges, and opportunities in the quantum industry directly from leading professionals.
- Students will develop the ability to build and maintain professional networks with industry leaders and peers in the quantum engineering field.
- Students will be able to identify how theoretical concepts in quantum engineering are applied in various industry sectors.
- Students will enhance their awareness of the skills and expertise required by employers in the quantum industry, improving their job readiness.
- Students will cultivate an entrepreneurial mindset by analyzing how quantum technologies can be commercialized and brought to market.
- Students will improve their ability to engage in meaningful discussions with industry experts, enhancing their professional communication skills.

PHGN527. QUANTUM ENGINEERING SEMINAR (SPRING). 1.0 Semester Hr.
The Quantum Engineering Seminar Series offers graduate students an opportunity to engage with leading professionals from the quantum industry. Through a series of guest lectures, students will explore cutting-edge developments in quantum technology, including quantum computing, sensing, materials, and communications. The course emphasizes professional development by fostering networking skills, enhancing career readiness, and encouraging interdisciplinary collaboration. Students will be encouraged to develop a ‘portfolio’ with summaries of discussions, follow up correspondence with speakers, and reflections on how they see their future careers in this field. This seminar series aligns with the Mines@150 mission, preparing students to become innovative leaders in the evolving field of quantum engineering.
Course Learning Outcomes

- Students will gain an understanding of current trends, challenges, and opportunities in the quantum industry directly from leading professionals.
- Students will develop the ability to build and maintain professional networks with industry leaders and peers in the quantum engineering field.
- Students will be able to identify how theoretical concepts in quantum engineering are applied in various industry sectors.
- Students will enhance their awareness of the skills and expertise required by employers in the quantum industry, improving their job readiness.
- Students will cultivate an entrepreneurial mindset by analyzing how quantum technologies can be commercialized and brought to market.
- Students will improve their ability to engage in meaningful discussions with industry experts, enhancing their professional communication skills.

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. 0-3 Semester Hr.
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. Prerequiste: 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.

PHGN597. SUMMER PROGRAMS. 0-6 Semester Hr.

PHGN598. SPECIAL TOPICS. 0-6 Semester Hr.
(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.

PHGN598. SPECIAL TOPICS. 0-6 Semester Hr.

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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.

PHGN599. INDEPENDENT STUDY. 0.5-6 Semester Hr.

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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. 0-6 Semester Hr.
(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.

PHGN699. INDEPENDENT STUDY. 0.5-6 Semester Hr.

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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.

Professors

Lincoln D. Carr

Patrice Genevet

Charles G. Durfee III

Uwe Greife

Mark T. Lusk

Frederic Sarazin, Department Head

Jeff A. Squier

Eric S. Toberer, Director of Materials Science

Lawrence R. Wiencke

Associate Professors

Daniel Adams

Zhexuan Gong

Eliot Kapit

Kyle G. Leach

Timothy R. Ohno

Meenakshi Singh

Jeramy D. Zimmerman

Assistant Professors

Eric Mayotte

Wouter Van de Pontseele

Teaching Professors

Kristine E. Callan

Alex T. Flournoy (deceased)

Patrick B. Kohl

H. Vincent Kuo, Assoc Dept Head, Director of UG Studies

Todd G. Ruskell

Charles A. Stone

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