

PHYSICS

Department Website:

<https://www.haverford.edu/physics>

Physics is the basis for our understanding of the universe, from the tiniest sub-atomic particles, to the way our bodies work, to the structure of the cosmos. It is essential for applications that permeate our lives, such as efficient industrial processes, cell phones, magnetic resonance imaging, and the internet. It drives the innovations that will shape our future, including quantum computing, exotic materials, and artificial intelligence.

We have structured our programs to be sufficiently flexible that they accommodate students wishing to study abroad, or to combine physics with other fields of study, such as medicine and interdisciplinary programs in astrophysics, biophysics, chemical physics, computing, and engineering.

Learning Goals

We expect that physics students should be able to solve problems independently, not only by applying equations to solve standard problems, but also by translating their knowledge into solutions of novel physical scenarios. Students are expected to acquire content knowledge, both conceptual and quantitative, as well as skills (e.g., the use of mathematical tools such as Fourier analysis, and computer methods for solving equations) appropriate for each course. Our laboratories, for instance, require substantial independent hands-on experimental work, teamwork, data analysis and reporting (in the form of a journal article in our advanced laboratories), and oral reporting, to allow the instructor to assess the level of understanding and performance of each student.

Haverford's Institutional Learning Goals are available on the President's website, at <http://hav.to/learninggoals>.

Curriculum

The department offers a unified coherent curriculum through the first two years, covering mechanics, thermal physics, waves, optics, electricity and magnetism, fluid mechanics, quantum mechanics and special relativity. We provide several different paths to enter the study of physics to accommodate differing levels of preparation and other academic interests. After the second year, we encourage students to select among course options according to their interests, so the actual content of the program can be different for different students. All students receive advanced training in at least three of the foundational areas of physics (including

mechanics, electricity and magnetism, thermal and statistical physics and quantum mechanics). We also provide opportunities to participate in original research with faculty members early in the curriculum; all majors must pursue a senior thesis research project.

We advise prospective majors in all of the science disciplines to study some physics in their first or second year at Haverford, given that all contemporary sciences rely heavily on basic physical principles. There are three different introductory options:

- PHYS H101 and PHYS H102 constitute a year-long, self-contained treatment of all of physics, with particular attention to applications in the life sciences.
- PHYS H105 and PHYS H106 use calculus somewhat more intensively and are designed for students who expect to continue their study of physics in other courses, in the physics, astronomy, or chemistry departments.
- PHYS H115 (followed by PHYS H106) provides a third option, designed for students with advanced preparation. Advice on course selection is provided on the department's web site.

A typical course sequence introducing both the physics major and minor consists of

Code	Title	Credits
PHYS H105 or PHYS H115	Fundamental Physics I	1.0
PHYS H106	Fundamental Physics II	1.0
PHYS H213 & PHYS H211	Waves and Optics and Laboratory in Electronics, Waves and Optics	1.5
PHYS H214 & PHYS H301	Introductory Quantum Mechanics and Quantum Physics Laboratory	1.5

However, students beginning their study in PHYS H101 and H102 may continue with PHYS H213 and join the major or minor as well.

PHYS H105 (or H115), H106, H213, and H214 are also prerequisites for the astronomy and astrophysics majors.

PHYS H213 and H214 and their associated laboratories (PHYS H211 and H301) serve as an introduction to waves, electronics, optics, mathematical methods in physics and quantum physics. We also offer a set of 300-level lecture courses covering core areas of physics as well as advanced topics courses that vary from year to year on topics including solid state physics, biological physics, computational physics, particle physics

and general relativity. Departmental astrophysics course offerings are described in the catalog under Astronomy and Astrophysics.

For students with little or no prior computer programming experience, and who do not intend to take CMSC105, we advise (but do not require) taking ASTR 104 / PHYS 104 in the first or second year. (Students who do well in this course can, if desired, go on to take CMSC107.)

In addition to concentrated study in core areas of physics, the department emphasizes student participation in research with faculty members. Currently, we have active research programs in soft condensed matter and granular physics, astroparticle and early Universe physics, extragalactic astronomy, gravity wave physics, biological physics, and nanoscience. Courses numbered PHYS H411 to H415 and ASTR H404 provide majors with opportunities to participate in these research efforts for academic credit during their senior year. Paid summer research positions are often available.

Advanced students interested in teaching may participate in the instructional program by registering for PHYS H459 or PHYS H460. (Students interested in physics or science education at the secondary level should also consult the teaching certification information in the section on Education and Educational Studies.)

Major Requirements

Physics offers a major and a minor. Students who wish to apply credits from outside the Quaker Consortium toward the major or minor requirements must consult with the department chair before taking such courses.

Physics Major Requirements

- PHYS H105 (or PHYS H101), and PHYS H106 (or PHYS H102).
- PHYS H213 and PHYS H214 (our sophomore lecture course sequence) and PHYS H211 (sophomore-level laboratory course).
- MATH H121 (or MATH H216) and MATH H215 (or one of: MATH H222, MATH B203 [the Bryn Mawr equivalent of MATH H215], or another 200-level mathematics course with permission).
- Three 300-level physics lecture courses, two of which must be drawn from these core courses: PHYS H302, PHYS H303, PHYS H308, and PHYS H309 (or their Bryn Mawr equivalents).
- An upper-level laboratory course in the natural or applied sciences, such as PHYS H301, ASTR H341, BIOL H300 or BIOL H301, or CHEM H301 or CHEM H302. (Alternately, the student can request

the substitution of an advanced laboratory course in another area of science or applied science.)

- Senior Seminar (PHYS H399F and PHYS H399I) and the associated senior talk and thesis.

For students considering graduate study in physics, it's helpful to take all of the core theory courses: PHYS H302, H303, H308, and H309 (or their Bryn Mawr equivalents; note that the Bryn Mawr version of 308 has much less emphasis on fluids). For students interested in graduate study in experimental physics, it is helpful to also take H326. For students interested in graduate study in theoretical/computational, it is helpful to also take a course relating to scientific computing, such as PHYS H304 or MATH H222. Any student interested in graduate study in any field should consult with their advisor for the courses that make the most sense for their particular case.

Senior Project

The senior research program demonstrates achievement in depth in a particular subfield of physics or astrophysics. Students participate in PHYS H399, a year-long, $\frac{1}{2}$ credit per semester senior seminar. We assess students by their performance on a short talk during the fall semester, a comprehensive talk or poster presentation in the spring semester and a senior thesis written in the form of a scientific paper.

In addition, as part of the year-long senior seminar, senior physics majors study topics in scientific integrity in two student-led meetings, using readings and role-playing scenarios to learn best practices in the ethical conduct of research. They also receive training in life after Haverford, including how to choose and apply to graduate schools, and what careers are available outside science for physics majors.

Students are expected to place their senior research work in the context of the scientific literature in their field of study, and to present their results to an audience of professionals (for their thesis) and their peers (for the talk or poster). They are given training in searching and reading the scientific literature by each research supervisor, as well as specific materials through the senior seminar course.

Most students also take a senior research course for credit (though this is not required). Their work in this course also assesses their research accomplishments.

Senior Project Learning Goals

We expect senior research in physics to demonstrate:

- a clear understanding of the scientific context of the research (including a review of the relevant scientific literature).
- mastery of the content and findings of the research.
- independent problem solving and ability to synthesize material.
- an understanding of the forward looking implications of the research findings.
- clarity in the public presentation of the research.

Senior Project Assessment

The evaluation of students' overall work in the senior seminar includes both their content knowledge in their research area, and their ability to communicate this work. In the fall semester, students write up the introduction and background sections of their senior thesis while getting training in researching and reading the scientific literature and properly referencing their bibliographic sources. They receive formative assessment from their senior thesis advisor on the fall paper, including suggestions for improvements on the final thesis. For the senior thesis, there are multiple rounds of assessment, since students get ongoing feedback from their research supervisors while writing their thesis, and they submit two distinct formal drafts which are read carefully by two faculty members who give extensive feedback. After each round, students must respond to this feedback while preparing their final thesis.

Similarly, each student gives a first short (10 minute) research talk in the fall and is given department-wide comments about how to improve this talk before they prepare and give their final senior presentation. Typically, each student practices each presentation several times, receiving detailed feedback from a supervisor in between to ensure they present their work at a level comparable with that of poster presentations and short talks at the American Physical Society or other comparable annual meetings.

The thesis research itself is evaluated for

1. a demonstrated understanding of the context and content of the research (including a review of the relevant scientific literature),
2. independent problem solving and synthesis, and
3. success in understanding the forward looking implications of the research.

The written and oral presentations of the research are evaluated for

1. a clear and appropriate writing style and
2. well-curated visual displays of the research.

A further confirmation of quality is the number of senior research projects that lead to publication in a peer-reviewed scientific journal.

Requirements for Honors

The departmental awards for honors in physics are based on the quality of performance in course work and the senior colloquium and paper. High honors carries the additional requirement of demonstrated originality in senior research.

Minor Requirements

- PHYS H105 (or PHYS H101 or PHYS H115) and PHYS H106 (or PHYS H102); PHYS H213, PHYS H214, and PHYS H211 lab (or Bryn Mawr equivalents).
- MATH H121 (or MATH H216) and MATH H215 (or one of: MATH H222, MATH B203 [the Bryn Mawr equivalent of MATH H215], or another 200-level mathematics course with permission).
- One of the four "core" 300-level lecture courses in physics at Haverford or Bryn Mawr: PHYS H302, PHYS H303, PHYS H308, or PHYS H309.

Concentrations and Interdisciplinary Minors

Physics majors can pursue a concentration in scientific computing.

Physics majors with biological interests may also qualify for the biophysics concentration.

Physics majors may also take an area of concentration in education.

Each of these concentrations is described in its relevant section of the Catalog.

Affiliated Programs

Physics majors should also consider study in our astronomy and astrophysics program. Students may pursue combined study by majoring in astrophysics, or by combining a physics major with either a major or minor in astronomy.

Students interested in engineering can complete an individualized major program in preparation for graduate work in engineering or the Engineering 4+1 Program with the University of Pennsylvania or the 3/2 Program with Caltech; for details see the Engineering section.

Students interested in materials science should also consult the related offerings in materials chemistry through Haverford's Department of Chemistry.

Study Abroad

Physics majors can and do pursue studies abroad. There are a number of programs, mostly in English-speaking countries, that allow physics majors to continue and broaden their studies in the field while abroad. Majors may count courses taken abroad toward the major with advanced permission; typically two to three courses may be granted credit in this way. Students interested in studying abroad should discuss this point with their major/pre-major advisor in advance.

Facilities

See the departmental web page for a description of laboratories, equipment and other special facilities for this program.

Faculty

Suzanne Amador Kane

The John and Barbara Bush Professor in the Natural Sciences; Professor of Physics and Astronomy; Coordinator of Biochemistry and Biophysics

Steve Boughn

Assistant Professor of Physics and Astronomy

Ted Brzinski

Assistant Professor of Physics and Astronomy

Daniel Grin

Assistant Professor of Physics and Astronomy

Wynn Ho

Research Associate

Andrea Lommen

The John Farnum Professor; Professor of Physics and Astronomy

Karen Masters

Professor of Physics and Astronomy; Director of Marian E. Koshland Integrated Natural Sciences Center

Bruce Partridge

Professor Emeritus of Astronomy

Walter Smith

The Paul and Sally Bolgiano Professor of Physics; Professor of Physics and Astronomy

David Stark

Visiting Professor

Paul Thorman

Physics Laboratory Instructor and Observatory Coordinator

Affiliated Faculty

David Wonnacott

Professor and Chair of Computer Science

Courses

PHYS H101 CLASSICAL AND MODERN PHYSICS I (1.0 Credit)

Deepika Khilnaney, Kazi Tawhid-Al-Islam, Suzanne Amador Kane, Walter Smith

Division: Natural Science; Quantitative

Domain(s): C: Physical and Natural Processes

Three class hours and one laboratory period. The first of a two-semester comprehensive introduction to physics, with an emphasis on life science applications involving Newtonian mechanics, oscillations, mechanics of materials, fluids, and thermal physics. Prerequisite(s): Calculus at the level of MATH H105 or equivalent should be taken prior to or concurrently with this course
(Offered: Fall 2022)

PHYS H102 CLASSICAL AND MODERN PHYSICS II (1.0 Credit)

Andrea Lommen

Division: Natural Science; Quantitative

Domain(s): C: Physical and Natural Processes

The second of a two-semester comprehensive introduction to physics, with an emphasis on life science applications involving electricity and magnetism, waves, electronics, waves and optics. Three class hours and one laboratory period. Prerequisite(s): PHYS H101 and MATH H105 or equivalent
(Offered: Spring 2023)

PHYS H105 FUNDAMENTAL PHYSICS I (1.0 Credit)

Andrea Lommen, Walter Smith, Staff

Division: Natural Science; Quantitative

Domain(s): C: Physical and Natural Processes

Three class hours and one laboratory period. Newtonian mechanics and thermodynamics. Applications are drawn primarily from the physical sciences. This sequence (105/106) is meant as a one-year introduction suitable for students interested in the physical sciences. Prerequisite(s): MATH 118 or equivalent (MATH 118 may be taken concurrently)
(Offered: Fall 2022, Spring 2023)

PHYS H106 FUNDAMENTAL PHYSICS II (1.0 Credit)

Andrea Lommen, Ted Brzinski, Staff

Division: Natural Science; Quantitative

Domain(s): C: Physical and Natural Processes

Electricity and magnetism, optics, electronics and special relativity. Applications are drawn primarily from the physical sciences. This sequence (105/106) is meant as a one-year introduction suitable for students interested in the physical sciences. Three class hours and one laboratory

period. Prerequisite(s): MATH H118 and PHYS H105 or equivalent
(Offered: Fall 2022, Spring 2023)

PHYS H211 LABORATORY IN ELECTRONICS, WAVES AND OPTICS (0.5 Credit)

Islam Khan, Kazi Tawhid-Al-Islam

Division: Natural Science

Domain(s): C: Physical and Natural Processes

The first half of this laboratory is an introduction to analog electronics and instrumentation. The second half includes experiments in waves and optics.

Prerequisite(s): PHYS H213 must either be taken concurrently or as a prerequisite

(Offered: Fall 2022)

PHYS H213 WAVES AND OPTICS (1.0 Credit)

Daniel Grin

Division: Natural Science; Quantitative

Domain(s): C: Physical and Natural Processes

Vibrations and waves in mechanical, electronic, and optical systems with an introduction to related mathematical methods such as functions of a complex variable and Fourier analysis. Topics include free and driven oscillations, resonance, superposition, coupled oscillators and normal modes, traveling waves, Maxwell's equations and electromagnetic waves, interference, and diffraction. PHYS H211, a related laboratory half-course, is normally taken concurrently and is required for majors. Prerequisite(s): PHYS H106 and MATH H118 or equivalent

(Offered: Fall 2022)

PHYS H214 INTRODUCTORY QUANTUM MECHANICS (1.0 Credit)

Staff

Division: Natural Science; Quantitative

Domain(s): C: Physical and Natural Processes

Introduction to the principles governing systems at the atomic scale. Topics include the experimental basis of quantum mechanics, wave-particle duality, Schrodinger's equation and solutions in one dimension, time dependence of quantum states, angular momentum, and one-electron atoms. Recent developments, such as paradoxes calling attention to the remarkable behavior of quantum systems, or quantum computing, will be discussed. Multi-electron atoms and nuclei will be considered if time allows. We recommend taking Physics 301, a related laboratory half-course, concurrently. Prerequisite(s): PHYS H213 or PHYS B308; we strongly recommend taking MATH H215 (Linear Algebra) or the equivalent before PHYS 214

(Offered: Spring 2023)

PHYS H301 QUANTUM PHYSICS LABORATORY (0.5 Credit)

Ted Brzinski, Staff

Division: Natural Science; Quantitative

Domain(s): C: Physical and Natural Processes

A full-semester weekly laboratory focusing on experiments of modern relevance with a focus on quantum mechanics. Topics may include: how lasers work and laser spectroscopy; spin resonance; nuclear and cosmic ray physics; electron diffraction; photoelectric effect; superconductivity; quantum eraser (a "which way" experiment); and others.

This is one of two laboratories at the advanced level required for the regular physics major and fulfills the advanced laboratory requirement for the interdisciplinary physics major. Prerequisite(s): PHYS H211; Co-requisite: PHYS 214

(Offered: Spring 2023)

PHYS H302 ADVANCED QUANTUM MECHANICS (1.0 Credit)

Walter Smith

Division: Natural Science

Domain(s): C: Physical and Natural Processes

A continuation of the study of quantum mechanics begun in 214. Topics include matrix mechanics and spin, many-particle systems, perturbation theory and scattering theory. A variety of physical systems will be treated as examples, such as simple atoms, neutrino oscillations, and solids. Prerequisite(s): PHYS 214 and either PHYS H213 or PHYS B306

(Offered: Spring 2023)

PHYS H303 STATISTICAL PHYSICS (1.0 Credit)

Ted Brzinski

Division: Natural Science

Domain(s): C: Physical and Natural Processes

Treatment of many body systems using classical and quantum statistics and ensembles to derive the laws of thermodynamics and statistical mechanics.

This course includes applications to the thermal properties of matter (solids, liquids and gases), photon, and phonon systems. Prerequisite(s): PHYS H214 and either PHYS H213 or PHYS B306

PHYS H304 COMPUTATIONAL PHYSICS (1.0 Credit)

Daniel Grin

Division: Natural Science

Domain(s): C: Physical and Natural Processes

An introduction to the methods and problems of computational physics, including matrix methods, ordinary differential equations, integration, eigensystems, Monte Carlo techniques, Fourier analysis, and iterative methods. Course will include a substantial independent project. Crosslisted: Physics, Astronomy, Computer Science Prerequisite(s): PHYS 213 or BMC PHYS 306 or instructor consent

(Offered: Spring 2023)

PHYS H308 MECHANICS OF DISCRETE AND CONTINUOUS SYSTEMS (1.0 Credit)

Ted Brzinski

Division: Natural Science

Domain(s): C: Physical and Natural Processes

Classical mechanics of systems of particles, conservation laws, Lagrangian mechanics, motion in central potentials, and core elements of chaos/non-linear dynamics. Fluid mechanics, covering the assumptions of the fluid approximation, key conservation laws, laminar, creeping, turbulent flow, and special topics like convection, waves, vortices, rotating flows, instabilities, flight, and biological flows as time and interest permit. Prerequisite(s): Either PHYS H213 or PHYS B306

(Offered: Fall 2022)

PHYS H309 ADVANCED ELECTROMAGNETISM (1.0 Credit)

Andrea Lommen

Division: Natural Science

Domain(s): C: Physical and Natural Processes

Boundary value problems, multipole fields, dielectric and magnetic materials; electromagnetic waves, propagation in dielectric media, conductors and waveguides; gauge transformations, radiating systems. Prerequisite(s): PHYS 214 and either PHYS H213 or PHYS B306

PHYS H320 TOPICS IN BIOLOGICAL PHYSICS: BIOMECHANICS AND SENSORY ECOLOGY (1.0 Credit)

Suzanne Amador Kane

Division: Natural Science

A survey of physical methods used to study problems in human, animal and plant biomechanics and sensory ecology. The class will be run seminar-style and will include student-led discussions of readings in a textbook and in the research literature. Assignments will include problem sets, laboratories and a final modeling or experimental project exploring a topic of the student's choice. Prerequisite(s): MATH H121 and at least two 200-level courses in either physics or biology

(Offered: Fall 2022)

PHYS H326 ADVANCED PHYSICS LABORATORY (1.0 Credit)

Walter Smith

Division: Natural Science

Domain(s): C: Physical and Natural Processes

Design, execution, and analysis of significant experiments, including experiments on fundamental techniques such as low-noise electronic measurements, optics, and computer interfacing, as well as more advanced experiments which

change from year to year. These include studies of microfluidics, atomic spectroscopy, cosmic ray physics, superconductivity, sensor technologies, and chaotic dynamics. Prerequisite(s): PHYS H301, PHYS 214 and either PHYS H213 or PHYS B306

(Offered: Fall 2022)

PHYS H351 TOPICS IN ASTROPHYSICS: GRAVITATIONAL WAVES (0.5 Credit)

Andrea Lommen

Division: Natural Science

Domain(s): C: Physical and Natural Processes

This course explores the new field of Gravitational Wave Astrophysics from the low frequencies (in the polarization of the cosmic microwave background) to the high frequencies that LIGO has discovered. In between, there is pulsar timing as a gravitational wave detector, and the planned space-based detector LISA. We will discuss how these different detectors will work together to explore the relatively unexplored gravitational wave universe. You will learn some of the basics of general relativity. Crosslisted: PHYS. Pre-requisite(s): PHY213 and PHY214 or permission of the instructor.

PHYS H352 TOPICS IN ASTROPHYSICS: EXTRAGALACTIC DATA SCIENCE (0.5 Credit)

Karen Masters

Division: Natural Science

Domain(s): C: Physical and Natural Processes

A 0.5 credit upper level astronomy/astrophysics elective, which can be taken in series with the other 0.5 credit upper level Astro elective offered the same semester, or as a stand-alone course. This class will cover the basics of modern extragalactic science (a review of our knowledge of the Milky Way and external galaxies) alongside hands on projects involving data science/statistical techniques used to investigate them. Assessment will be highly project based, with regular coding assignments (in python) done during class time, and guided reading of both current, and classic astrophysical literature. Students will leave with an understanding of extragalactic astrophysics as a modern data focused science. Crosslisted: PHYS. Pre-requisite(s): ASTR204

PHYS H353 TOPICS IN PHYSICS: SOFT MATTER PHYSICS (0.5 Credit)

Ted Brzinski

Division: Natural Science

Domain(s): C: Physical and Natural Processes

This is a 1/2-credit, upper-level physics elective course which serves as an introduction to the physics of soft condensed matter (squishy stuff!), and will comprise a mixture of seminar-style discussions and chalk talk-like student presentations. Seminar discussions will center around peer-reviewed literature and conference lecture recordings.

Students will finish the course having developed general literacy with the core concepts in Soft Matter and an understanding of the major challenges facing professional Soft Matter scientists. During a given semester, the course may follow a narrower theme, like "The Soft Matter Physics of Coffee," or "The Earth as Soft Matter". Crosslisted: ASTR. Pre-requisite(s): Math H121, at least two 200-level courses in physics or another natural science Lottery Preference: Physics majors, astrophysics majors, astro majors and physics/astro minors, seniors, juniors.

PHYS H354 TOPICS IN PHYSICS/ASTRONOMY: PHYSICAL COSMOLOGY THROUGH COMPUTATION (0.5 Credit)

Daniel Grin

Division: Natural Science; Quantitative

Domain(s): C: Physical and Natural Processes

This class will introduce cosmological expansion, fluid dynamics of the homogeneous and perturbed universe, and stochastic processes in the universe. Students will build computational problem-solving skills related to these concepts, coming to an understanding of how modern precision measurements of the cosmic microwave background and galaxy density field unveil the energy budget of the universe, which includes mysterious dark matter and dark-energy components. Crosslisted: ASTR. Pre-requisite(s): Physics 213 Lottery Preference: Juniors and seniors in physics, astrophysics, and astronomy majors.

PHYS H399F SENIOR SEMINAR (0.5 Credit)

Walter Smith

A capstone experience for seniors in physics and astrophysics meeting biweekly throughout the year. An introduction to scientific writing and speaking; scientific ethics; graduate study in physics and astronomy; career options for physics and astronomy majors, both within the field and outside science; preparation and presentation of senior papers and colloquia; attendance at lectures by distinguished visitors; and discussions of student and faculty research projects in the department. This course is graded universal P/F in which no numerical grade is assigned. Prerequisite(s): Senior standing in physics or astrophysics
(Offered: Fall 2022)

PHYS H399I SENIOR SEMINAR (0.5 Credit)

Andrea Lommen

A capstone experience for seniors in physics and astrophysics meeting biweekly throughout the year. An introduction to scientific writing and speaking; scientific ethics; graduate study in physics and astronomy; career options for physics and astronomy majors, both within the field and outside science; preparation and presentation of senior papers and

colloquia; attendance at lectures by distinguished visitors; and discussions of student and faculty research projects in the department. This course is graded universal P/F in which no numerical grade is assigned. Prerequisite(s): Senior standing in physics or astrophysics
(Offered: Spring 2023)

PHYS H404 RESEARCH IN ASTROPHYSICS (1.0 Credit)

Andrea Lommen, Karen Masters

Division: Natural Science

Intended for those students who choose to complete an independent research project in astrophysics under the supervision of a faculty member.

Prerequisite(s): Instructor consent

(Offered: Fall 2022)

PHYS H411 RESEARCH IN SOFT MATTER PHYSICS (1.0 Credit)

Ted Brzinski

Division: Natural Science

Experimental research studying the rigidity and failure of jammed, disordered solids, and the mechanical response of athermal and nonlinear materials. Prerequisite(s): Instructor consent
(Offered: Fall 2022, Spring 2023)

PHYS H412 RESEARCH IN THEORETICAL AND COMPUTATIONAL PHYSICS (1.0 Credit)

Daniel Grin

Independent research on current problems in theoretical physics, with emphasis on particle physics, physical cosmology, and mathematical physics; extensive use is also made of computer-based methods. This course is graded universal P/F in which no numerical grade is assigned.

Prerequisite(s): Instructor consent

(Offered: Fall 2022)

PHYS H413 RESEARCH IN BIOLOGICAL PHYSICS (1.0 Credit)

Suzanne Amador Kane

Experimental & computational research applying physics to problems in biomechanics, animal behavior & sensory ecology. This course is graded universal P/F in which no numerical grade is assigned. Prerequisite(s): Instructor consent

(Offered: Fall 2022)

PHYS H415 RESEARCH IN NANOSCALE PHYSICS (1.0 Credit)

Walter Smith

Division: Natural Science

Research on the morphology and electronic properties of nano-scale materials. Prerequisite(s): Instructor consent. Advanced lab experience preferred

(Offered: Fall 2022)

**PHYS H459 TEACHING LABORATORY
PHYSICS (1.0 Credit)**

Division: Natural Science

Study of the principles and practices of laboratory instruction in physics through association with staff in the Physics 102 laboratory. The student will interact with students in the laboratory sessions, prepare and deliver a pre-laboratory lecture, critique the descriptive materials for at least one experiment, and develop a new experiment appropriate to the course. This development work will include both written materials and the design and construction of a working prototype. This experiment and the 102 laboratory program as a whole will be evaluated in a final paper. Prerequisite(s): Senior standing in Physics, Astrophysics or Astronomy and instructor consent.

(Offered: Spring 2023)

**PHYS H460 ASSOCIATION IN TEACHING BASIC
PHYSICS (1.0 Credit)**

Division: Natural Science

Study of the principles and practices of lecture instruction in physics through association with staff in Physics 101. The student will attend and critique course lectures; prepare, practice, and deliver a lecture; develop a lecture demonstration to be used in his or her lecture; participate in the preparation of examination problems and their evaluation; address student questions in the physics clinic; and write an evaluative final paper. Prerequisite(s): Senior standing in Physics, Astrophysics or Astronomy and instructor consent.

(Offered: Fall 2022)

PHYS H480 INDEPENDENT STUDY (1.0 Credit)

Andrea Lommen

Division: Natural Science

Intended for students who want to pursue some topic of study that is not currently offered in the curriculum. In order to enroll, a student must have a faculty sponsor. Prerequisite(s): Instructor consent

(Offered: Fall 2022)