PHYSICS

In the Department of Physics and Astronomy

***Chair,** Associate Professor Jonathan McCoy*
Professors Robert Bluhm, Charles Conover, and Duncan Tate; Associate Professors Dale Kocevski, Jonathan McCoy, and Elizabeth McGrath; Senior Laboratory Instructor Lisa Lessard; Laboratory Instructor I Michaela Allen

The Department of Physics and Astronomy offers several programs. Students may select one of the following: (1) the physics major, (2) the physics major with a concentration in astrophysics, (3) the astronomy minor, and (4) the physics minor. The astronomy minor is described in the "Astronomy" section of the catalogue.

Physicists study nature and how things work on levels ranging from the smallest subatomic and atomic scales, through intermediate scales describing matter in its various forms, up to the largest astrophysical scales of galaxies and the universe as a whole. Physics and astronomy students acquire skills in qualitative descriptions and explanations of physical phenomena, mathematical analysis of physical phenomena, experimental observation, measurement, and instrumentation, theoretical and numerical modeling, scientific writing, and oral presentation. Flexible major and minor programs are designed to fit within a liberal arts education and to provide preparation for careers or advanced training in science, teaching, business, medical professions, and engineering. The department welcomes students from all majors and with diverse backgrounds.

The introductory course sequence, Physics 141 (or 143) and 145, provides a solid basis for further work in physics as well as preparation for medical school and advanced study in other sciences. These courses also provide excellent preparation for students who plan to enter professions such as law, teaching, and business. The intermediate and advanced course offerings in the department provide a strong background for graduate study in physics, astronomy, engineering, and interdisciplinary fields such as biophysics, neuroscience, environmental science, medical physics, and bioengineering.

All faculty members have active research programs that involve undergraduate contributions. Faculty research areas include atomic, molecular, and optical physics, condensed-matter physics, theoretical physics, and astronomy. Research projects make use of the department's well-equipped laboratories, computer workstations, the Collins and Young Observatories, and supporting technical shops. Students interested in conducting research with faculty are encouraged to consider the Honors Programs that the department offers.

Students seeking a career in engineering may consider applying to an exchange program in which both a bachelor of arts and a bachelor of engineering can be earned upon successful completion of a joint program with Dartmouth College or Columbia University. Interested students should consult with the engineering advisor before selecting their first-semester courses.

Physics 141, 145, 241, and 242 form a comprehensive introduction to classical and modern physics. For students with a previous background in physics and calculus from high school, Physics 143 may be taken instead of Physics 141.

No requirements for the physics major, the physics major with a concentration in astrophysics, or the physics minor may be taken satisfactory/unsatisfactory. Grade point averages for the department's majors and minors are calculated using all courses that can satisfy the requirements listed below.

Students considering graduate school in physics or astronomy are strongly encouraged to take all of the following courses: Mathematics 253, 262, 311, 352, Physics 253, 311, 321, 332, and 431.

Requirements for the Physics Major

Physics majors have a lot of flexibility in choosing the courses that are most appropriate for them. Students should work closely with their advisors in selecting courses to fulfill the requirements for the major and satisfy their academic goals. Not all upper-level elective courses are offered every year. Seniors must enroll in Physics 401.

Required Physics Courses (unless exempted by advanced placement)

Physics

- 141 Foundations of Mechanics (or 143 Honors Physics)
- 145 Foundations of Electromagnetism and Optics
- 241 Modern Physics I
- 242 Modern Physics II
- 250 Experiments in Modern Physics
- 401 Senior Physics and Astronomy Seminar

Mathematics and Computer Science Courses: Choose four (unless exempted by advanced placement); no more than one of the courses should be in computer science.

Computer Science (152 preferred over 151 or 153)

- 151 Computational Thinking: Visual Media
- 152 Computational Thinking: Science

- 153 Computational Thinking: Smart Systems

Mathematics

- 120, 121, 125, or 130 Single-Variable Calculus (or Honors Calculus I, 135 or 161)
- 122 or 160 Series and Multi-Variable Calculus (or Honors Calculus II, 162 or 165)
- 253 Linear Algebra
- 262 Vector Calculus
- 311 Ordinary Differential Equations

Elective Courses: Choose at least three. At least two must be 300-level or higher physics or astronomy courses, and at least one 300-level or higher physics or astronomy course must be taken at Colby.

Astronomy

- 231 Introduction to Astrophysics
- 342 Galaxies and Cosmology

Biology

- 274 Neurobiology

Chemistry

- 255 Nuclear Magnetic Resonance
- 341 Physical Chemistry: Thermodynamics and Kinetics

Mathematics

- 332 Numerical Analysis

Physics

- 253 Electronic Measurement in the Sciences
- 311 Classical Mechanics
- 312 Physics of Fluids
- 321 Electricity and Magnetism
- 332 Thermodynamics and Statistical Mechanics
- 333 Experimental Soft Matter Physics
- 335 General Relativity and Cosmology
- 338 Nuclear and Particle Physics
- 431 Quantum Mechanics

Requirements for the Physics Major with a Concentration in Astrophysics

Students should work closely with their advisors in selecting courses to fulfill the requirements for the concentration. Not all upper-level courses are offered every year. Astronomy 231 and one 300-level physics or astronomy course must be taken at Colby. Seniors must enroll in Physics 401. Students electing the astrophysics concentration should choose a class that focuses on a topic in astrophysics or a related field.

Required Courses (unless exempted by advanced placement)

Physics

- 141 Foundations of Mechanics (or 143 Honors Physics)
- 145 Foundations of Electromagnetism and Optics
- 241 Modern Physics I
- 242 Modern Physics II
- 250 Experiments in Modern Physics
- 401 Senior Physics and Astronomy Seminar

Astronomy

- 231 Introduction to Astrophysics
- 342 Galaxies and Cosmology

Computer Science – Choose one (152 preferred over 151 or 153)

- 151 Computational Thinking: Visual Media
- 152 Computational Thinking: Science
- 153 Computational Thinking: Smart Systems

Mathematics – Choose three (unless exempted by advanced placement)

- 120, 121, 125, or 130 Single-Variable Calculus (or Honors Calculus I, 135 or 161)
- 122 or 160 Series and Multi-Variable Calculus (or Honors Calculus II, 162 or 165)
- 253 Linear Algebra
- 262 Vector Calculus
- 311 Ordinary Differential Equations

Elective Courses: Choose at least two. At least one must be a 300-level or higher physics or astronomy course.

Computer Science

- 231 Data Structures and Algorithms
- 251 Data Analysis and Visualization

Mathematics

- 381 Mathematical Statistics I: Probability

Physics

- 311 Classical Mechanics
- 321 Electricity and Magnetism
- 332 Thermodynamics and Statistical Mechanics
- 335 General Relativity and Cosmology
- 338 Nuclear and Particle Physics
- 431 Quantum Mechanics

Statistics

- 212 Introduction to Statistical Methods
- 321 Applied Regression Modeling

Requirements for Honors in Physics and Physics with a Concentration in Astrophysics

In the junior year, physics majors may apply for admission to the honors program. A 3.25 grade point average in courses that can count toward the major is normally required. Successful completion of the honors program will result in the degree being awarded with “Honors in Physics” or “Honors in Physics with a Concentration in Astrophysics.”

Honors majors in physics must, in addition to fulfilling the requirements for the major, take three additional 300-level or higher physics courses and one additional 200-level or higher mathematics course. In fulfilling these requirements, students must take at least one upper-level experimental course (Astronomy 231, Physics 253 or 333). In their senior year, they must also take Physics 483 and 484 Independent Honors Project. A written honors thesis is required. A thesis completed as part of the Senior Scholars Program may be substituted for the honors thesis.

Honors majors with a concentration in astrophysics must, in addition to fulfilling the requirements for the concentration, take three additional electives, two of which must be 300-level or higher physics or astronomy courses. In their senior year, they must also take Physics 483 and 484 Independent Honors Project. A written honors thesis is required. It is expected that students electing the astrophysics concentration will focus their honors thesis on a topic in astrophysics.

Requirements for the Minor in Physics

Physics 141 (or 143), 145, 241, 242 (or 300-level or higher physics or astronomy course), Mathematics 121 (or 120, 125, 130, 135, or 161), 122 (or 160, 162, or 165).

Note: Students cannot fulfill the physics minor if electing to minor in astronomy.

Course Offerings

[PH120] Space ... The Final Frontier This writing-intensive course will use the exploration of other worlds, real and imagined, as an opportunity to investigate the shifting relationships between science, science fiction, and fantasy. Students will consider the social and political implications of human exploration, together with the science behind space travel and the historical development of the NASA space program in particular. Literature and films will be treated as texts, illustrating key elements of written craftsmanship such as word choice, style, structure, and narrative. *Four credit hours.* **W1.**

PH141f Foundations of Mechanics A calculus-based survey of classical Newtonian mechanics, including kinematics, forces, work and energy, momentum, gravity, fluids, oscillations, and waves. These topics are developed further in discussions, labs, and problem-solving assignments. May not be taken for credit if the student has earned credit for Physics 143. *Prerequisite:* A working knowledge of high school

or college calculus, or concurrent enrollment in Mathematics 121, 122, 125, 130, MA160, or 161. *Four credit hours.* **N, Lb.** CONOVER

PH143f Honors Physics An accelerated, calculus-based, introductory course on Newtonian mechanics supplemented with some coverage of additional special topics. Intended for students who have had substantial courses in physics and calculus in high school. Topics in Newtonian mechanics include kinematics, dynamics, conservation laws, oscillations, and waves. Additional topics include special relativity and nuclear physics. Students acquire knowledge in these areas and skills for solving mathematical problems and doing laboratory work. May not be taken for credit if the student has earned credit for Physics 141. *Four credit hours.* **N, Lb.** BLUHM

PH145s Foundations of Electromagnetism and Optics Explores the foundations of electrical and magnetic forces, electromagnetic waves, and optics. Students will learn how electric and magnetic fields are described mathematically, how they are interrelated, and how the interrelations lead to a wide variety of physical phenomena. Practical applications in electric circuits and optical devices are explored. These topics are developed further in discussions, laboratory exercises, and out-of-class assignments. *Prerequisite:* Physics 141 or 143, and Mathematics 121, 125, 130, 135, or 161. *Four credit hours.* **N, Lb.** MCCOY, TATE

PH231f Introduction to Astrophysics Listed as Astronomy 231. *Four credit hours.* **N, Lb.** ALLEN, MCGRATH

PH241f Modern Physics I An introduction to the two central paradigms of non-Newtonian physics: Einstein's special theory of relativity and the quantum behavior of light and matter. The postulates of Einstein are presented and the consequences explored theoretically along with experimental evidence for relativity. The experimental evidence for quantum mechanics is considered from a historical perspective, beginning with Planck's quantum hypothesis for blackbody radiation through to the Bohr model of the hydrogen atom and the experimental evidence for the Schrödinger equation. Students will acquire skills in solving physics problems and learning to communicate the solutions effectively in writing. Lecture and discussion. *Prerequisite:* Physics 145 and Mathematics 122, 160, 162 or 165. *Four credit hours.* MCCOY

PH242s Modern Physics II An intermediate-level introduction to quantum mechanics and atomic physics. Topics include the Schrödinger equation, interpretation of the wave function, one-dimensional potentials, hydrogen atom, electron spin, exclusion principle, atomic structure, and atomic spectra. Lectures and discussions. *Prerequisite:* Physics 241. *Four credit hours.* CONOVER

PH250fs Experiments in Modern Physics Explores physics laboratory practice in connection with the core principles of modern physics. Introduces concepts of experiment design, the use of electronic instrumentation and data acquisition, techniques of data analysis and presentation, and skills in scientific communication through written and/or oral presentations. Lecture and laboratory. *Prerequisite:* Physics 241 (may be taken concurrently). *Four credit hours.* MCCOY, TATE

[PH253] Electronic Measurement in the Sciences Electronic measurements are used in all of the sciences as well as interdisciplinary research areas such as environmental science. Provides introduction to control and measurement instrumentation using analog and digital devices and microcontrollers. Emphasizes laboratory work and includes design and implementation of electronic measurement and signal processing methods. Advanced analysis techniques will be introduced. Normally offered every other year. *Prerequisite:* Physics 145. *Three credit hours.*

[PH262] Data Science in Astrophysics Listed as Astronomy 262. *Four credit hours.*

PH311f Classical Mechanics Newton's laws, oscillatory motion, noninertial reference systems, classical gravitation, motion of rigid bodies, and Lagrangian and Hamiltonian mechanics. Lecture and discussion. *Prerequisite:* Physics 145 and Mathematics 122, 160, 162 or 165. *Four credit hours.* TATE

[PH312] Physics of Fluids All living things, from the smallest cells to the largest communities, interact with the fluid environment of liquids and gases that covers the planet. Our understanding of fluid motion helps us build better airplanes, investigate climate change, and discover new design principles in biology. We will view this subject as an exciting, interdisciplinary opportunity to see the laws of physics in action. Emphasis will be on a core set of basic concepts and mathematical tools used to describe fluids and explore a range of applications drawn from biology, chemistry, geophysics, and engineering. *Prerequisite:* Mathematics 262 and Physics 242. *Four credit hours.*

PH321f Electricity and Magnetism A theoretical treatment of electrostatics and magnetostatics in vacuum and material media through Maxwell's equations. Lecture and discussion. *Prerequisite:* Physics 145 and Mathematics 262. *Four credit hours.* MCELMURRY

PH332s Thermodynamics and Statistical Mechanics Examines the concepts of temperature, energy, heat, work, and entropy. Thermodynamic relations between these quantities are studied from both a microscopic and macroscopic point of view. The laws of

thermodynamics are developed from an underlying statistical treatment. Topics such as heat flows, heat engines, phase transitions, chemical reactions, Bose-Einstein and Fermi-Dirac statistics, and blackbody radiation are discussed. Lecture and discussion. *Prerequisite:* Mathematics 122, 160, 162, 165 and either Physics 242 (may be taken concurrently) or Chemistry 342 (may be taken concurrently). *Four credit hours.* MCGRATH

[PH333] Experimental Soft Matter Physics An introduction to scientific research, focusing on soft matter physics and nonlinear science. Uses advanced experimental topics such as Brownian motion, pattern formation, hydrodynamic instabilities, and chaos to provide basic training in modern interdisciplinary research methods. Strong emphasis will be placed on the use of computers and computer programming, image analysis, wet lab techniques, and other broadly applicable skills, including the reading and writing of scientific research articles. *Prerequisite:* Physics 242 and Mathematics 262. *Four credit hours.*

[PH334] Experimental Atomic Physics Experimental Atomic Physics Laboratory projects in modern atomic, molecular, and optical (AMO) physics. Experiments include observing the Zeeman effect in mercury using a grating spectrometer, laser-induced fluorescence spectroscopy of iodine, Doppler-free diode laser spectroscopy, and magneto-optical trapping of rubidium atoms. Through these and other projects, students will learn cutting-edge techniques of modern AMO physics. In addition they will become familiar with, and be expected to engage in, communication of results both orally and in written form. Laboratory and tutorial. Some out-of-class participation required. *Prerequisite:* Physics 242 and 250. *Four credit hours.*

[PH335] General Relativity and Cosmology An introduction to Einstein's general theory of relativity, including a treatment of tensor analysis, Einstein's equations, Schwarzschild metric, black holes, expansion of the universe, and cosmology. *Prerequisite:* Physics 241. *Four credit hours.*

PH342s Galaxies and Cosmology Listed as Astronomy 342. *Four credit hours.* KOCEVSKI

[PH345] Topics in Quantum Information Quantum information science combines physics and computer science. Exploiting the dynamics of quantum systems changes the nature of computation and manipulating information. The course will provide an introduction to the foundational principles of quantum physics from the perspective of quantum information including an understanding of the difference information storage in quantum states versus classical states (quantum bits and classical bits) including the inability to copy quantum bits (the no-cloning theorem) and entanglement, an understanding of quantum computing operations (quantum gates) an introduction to quantum algorithms, in particular those for factoring composite numbers and database searches. The course will be taught in a seminar format. Previously offered as Physics 398 (Spring 2020). *Prerequisite:* Mathematics 253 and Computer Science 232 or Physics 242. *Two credit hours.*

PH401f, 402s Senior Physics and Astronomy Seminar Seminars will focus on student-led discussions of readings from the primary literature and will also include playing host to outside speakers. Required of all senior physics majors. *Prerequisite:* Senior standing. *Two credit hours.* BLUHM, MCGRATH

PH401Sf Senior Physics and Astronomy Seminar *Noncredit.* BLUHM

PH431s Quantum Mechanics Study of the structure and interpretation of quantum mechanics at an advanced level. Quantum states and observables are described in terms of abstract state vectors and operators. Students learn about representations of state vectors and operators in terms of wave functions and differential operators in addition to the tools of linear algebra: vectors and matrices. We will approach the abstract representation of quantum objects using the concrete example of spin-1/2 particles and photons to provide insight into fundamental principles. Deep issues concerning the nature of locality and realism are explored. Weekly discussions and problem-solving assignments are used to clarify concepts. Should be taken by students intending to go to graduate school in physics or a related area. *Prerequisite:* Physics 242 and Mathematics 253. *Four credit hours.* BLUHM

PH483f Independent Honors Project Research conducted under the guidance of a faculty member and focused on an approved topic leading to the writing of an honors thesis. *Two to four credit hours.* FACULTY

PH491f, 492s Independent Study Individual topics or research in areas where the student has demonstrated the interest and competence necessary for independent work. *Prerequisite:* Permission of the instructor. *One to five credit hours.* FACULTY