Intramural Program

The Physical Education Department conducts a competitive intramural program of sports in season, including air hockey, badminton, basketball, beach volleyball, dodgeball, flag football, foosball, pool/billiards, racquetball, soccer (indoor and outdoor), softball, squash, tennis, tube water polo and volleyball.

Intercollegiate Athletics

Intercollegiate athletics represent an important educational component of the wide range of learning experiences provided by the College. Students may sign up for physical education credit for participation on the following intercollegiate teams. For women: basketball, cross country, golf, lacrosse, soccer, softball, swimming, tennis, track and field, volleyball and water polo. For men: baseball, basketball, cross country, football, golf, soccer, swimming, tennis, track and field and water polo.

Club Sports

Club sports, organized by students of the undergraduate Claremont Colleges, include badminton (coed), cycling (coed), equestrian, fencing (coed), lacrosse (men), racquetball, rugby (men/women), ultimate frisbee (men/women) and volleyball (men).

Physics and Astronomy Department

Professor Bryan Penprase, department chair

Professors Mawhorter, Mitescu[2], Moore, Penprase, Zook
Associate Professors Kwok, Tanenbaum
Assistant Professors Choi[3], Whitaker

Physics is the study of the most fundamental properties of matter and energy, stressing the quantitative description of nature. As such, it has close connections to and applications in mathematics, the other physical sciences, particularly chemistry and geology and increasingly in the life and medical sciences. Astronomy, the study of the formation and evolution of the large-scale universe, extends the laws of physics to the largest scales of both space and time and allows students to apply their knowledge of physics to the formation and structure of stars, galaxies and the early universe itself. Both physics and astronomy have also been important in Western intellectual history and the development of fields outside the sciences such as philosophy, religion, history and politics. Majoring in physics or astronomy also develops capabilities valuable in many "real life" situations: problem-solving skills, quantitative modeling and analysis skills, technical reading and writing skills, experimental design skills and oral presentation skills.

Student Research. An important aspect of the major is the required senior thesis. Majors are strongly encouraged to elect independent research projects, usually in conjunction with a faculty member's research program, which may be experimental, computational or theoretical. Recent thesis topics involving independent research have included carbon nanotubes, maskless lithography, optical tweezers, electron diffraction, computational general relativity, computational and experimental fluid dynamics, nonlinear dynamics and chaos, passive solar architecture and physics education research. Astronomy research projects have included monitoring active galactic nuclei, quasar absorption line spectroscopy, telescope instrument design, analyzing Spitzer and Hubble Space Telescope data and acquiring

[2]On leave Spring 2010 [3]On leave 2009-10

images of galaxies in infrared and optical wavelengths. Students may also carry out independent work earlier than the senior year as a summer research assistant or under Physics or Astronomy 199.

Career Opportunities. The Pomona College Physics Major prepares students for careers in a wide variety of fields. Persons with a good grounding in physics are employed in all fields of engineering, in basic and applied research in physics, materials science, astronomy, optics, chemical physics, geophysics and biophysics, as well as teaching, medicine and law. Many careers for astronomers exist in NASA and other research institutes, as well as in industrial settings where computer skills and image processing are important. A strong technical background is becoming increasingly useful in the fields of public policy, urban planning and environmental studies. Students interested in these fields may wish to investigate the program in science, technology and society (see listing), with a focus on physics.

Laboratory Facilities. The Pomona College Physics and Astronomy Department features some of the most advanced research-grade equipment in physics and astronomy for any undergraduate college. Major physics equipment includes facilities for electron scattering, cryogenics, high-Tc superconductivity, optical and scanned-probe microscopy, photolithography, ellipsometry, spectral reflectance, field emission scanning electron microscopy, electron beam lithography, energy dispersive X-ray analysis, atomic and molecular spectroscopy, nonlinear optics and holography, as well as laser tweezers, an all-optical system for producing Bose-Einstein condensates, a thin-film evaporator and a dedicated system for growing carbon nanotubes. The astronomy facilities include a research-grade one-meter telescope in the San Gabriel Mountains equipped with optical and infrared-wavelength CCD cameras, as well as an on-campus observatory equipped with two computer-controlled 14-inch telescopes and a variety of portable and solar telescopes. The department also features a professionally staffed machine and electronics shops to develop new instrumentation. Access to an X-ray diffractometer is available in cooperation with the Geology Department.

Major Requirements. The Department of Physics and Astronomy offers multiple tracks to suit diverse student interests. The physics and astrophysics tracks provide rigorous training for those students interested in graduate studies and research, while the astronomy and EPSS tracks train students more broadly in science for careers in teaching, technology and space science. In all four tracks, students receive a B.A. in physics upon graduation, but can choose different groups of physics and astronomy courses to suit their interests. The Physics and Astronomy Department is also actively involved in the environmental analysis and public policy programs. The degree requirements for all four tracks and for the two programs, are described below.

Requirements for the Major in Physics

A major in physics requires the completion of:

1) Physics Introductory Sequence (see below) and 101
2) 128, Electronics
3) MATH 60 and either MATH 32 or 107 (and prerequisites)
4) One non-Physics laboratory science course selected from the following:
   ASTR 51, 101; BIOL 40; CHEM 1A,B, or 51; GEOL 110; HM ENGR 4, 80, or 111. Other courses may be substituted with departmental approval.
5) At least three core courses
6) One other course chosen from core and upper-division elective courses
7) 174, Contemporary Experimental Physics
8) 190, Senior Seminar and 193, Senior Comprehensive Examination
9) 191, Senior Thesis

Courses taken to fulfill requirements for both the physics and astronomy majors must be taken on a letter grade basis.

A rich and varied weekly colloquium series is offered in conjunction with the Harvey Mudd College Physics Department. Junior and senior physics majors are expected to attend at least three-fourths of the Pomona College colloquia and student research/thesis presentations.

A student planning graduate work in physics should take all four core courses, as well as a broader selection of elective courses in physics and mathematics and should acquire a reading knowledge of at least one foreign language and some competence in computer programming. Modified programs within the Physics Major are also available for students interested in medicine and high school teaching. Students interested in chemical physics, engineering, geophysics and other specializations may wish to consider proposing a special major. See the department Web page at *www.physics.pomona.edu* for further information.

Requirements for a Minor in Physics

A minor in physics requires the completion of the physics introductory sequence (see below) including PHYS 101, MATH 60 and either MATH 32 or 107; at least one core course; and two other course credits chosen from core, upper-division laboratory and upper-division elective courses. Students may petition the department to elect the Pass/No Credit (P/NC) grading option for one course taken to fulfill a requirement for the minor.

Classification of Courses

Introductory courses: 41,42, 70, 71, 72 and 101
Core courses: 125, 142, 170 and 175
Upper-division elective courses: 148, 160 and 180. A student not electing the Astronomy Major or Minor can also count Astronomy (ASTR) 101 and any pair of the ASTR 120 half-course series as electives for the Physics Major or minor.
Other requirements for the Physics Major: 128, 174, 190, 191E or 191L, 193
Courses offered for non-majors: 3, 17

Requirements for the Astrophysics Track of the Physics Major

Students wishing to pursue the study of modern astronomy and astrophysics and particularly those preparing for graduate work in astronomy and astrophysics, should complete the astronomy track of the Physics Major. The requirements for this track are:

1. Physics Introductory Sequence (see below) and 101
2. ASTR 62 and ASTR 101
3. Two half-courses from the ASTR 120 series, ASTR 51 and one ASTR 120 half-course
4. Mathematics through MATH 60
5. At least two core PHYS courses (125, 142, 170, or 175)
6. One other course chosen from core and upper-division physics electives
7. PHYS 174, Contemporary Experimental Physics or 128, Electronics with Laboratory
8. PHYS 190, Senior Seminar and 193, Senior Comprehensive Examination
9. PHYS 191, Senior Thesis

Further aspects of the program may be planned in consultation with Mr. Penprase, Mr. Choi, or Ms. Zook.

Additional tracks of the Physics Major include the astronomy track and the earth, planetary and space science (EPSS) track. The astronomy track prepares students to be broadly educated in the sciences of astronomy and physics and is an ideal preparation for teaching, outreach or technical work in astronomy and related fields. The EPSS track blends astron-

omy, physics and geology and is intended for students who wish to pursue graduate studies and professional careers in planetary astronomy or space science. A similar track with a slightly different earth science and geology emphasis (i.e., disciplinary focus) is offered by the Geology Department. Further details on the program may be obtained from Mr. Penprase or Mr. Grosfils in the Geology Department.

Requirements for the Astronomy Track of the Physics Major

1. Physics Introductory Sequence (see below) and PHYS 101
2. Two introductory science courses: ASTR 1, 6 or 51; PHYS 3, 17; GEOL 20, other science courses with permission
3. One non-physics lab science course selected from the following: CSCI 51; CHEM 1 or 51; other courses with permission
4. ASTR 62, ASTR 101
5. Two half-courses from the ASTR 120 series
6. Mathematics through MATH 32
7. At least one additional upper-division (100 or above) ASTR, GEOL or PHYS course (PHYS 125, 142, or additional ASTR 120-series half-courses are recommended)
8. PHYS 190, Senior Seminar
9. PHYS 191, Senior Thesis

Requirements for the Earth, Planetary and Space Science (EPSS) Track of the Physics Major

1. Introductory courses: GEOL 20B; ASTR 51 or 62; Physics Introductory Sequence (see below); MATH 30, 31, 32
2. Disciplinary Focus in Astronomy: ASTR 101 and two of ASTR 120, 121, 123 or 124. Also requires PHYS 101, MATH 60 and GEOL 125, 110.
3. PHYS 190, Senior Seminar
4. PHYS 191, Senior Thesis

Requirements for a Minor in Astronomy

Students may complete a minor in astronomy by completing the physics introductory sequence (see below), ASTR 62 and 101 and two additional full courses from the lists below, with at least one coming from list 2.

1. ASTR 51
2. PHYS 101 or two advanced astrophysics half-courses (ASTR 120, 121, 123, 124)

Other Information

Physics Introductory Sequence: All students interested in the possibility of a physics, astrophysics, or astronomy major or minor should take 70 during their first year, if at all possible. During this course, students will take a test that will assess the strength of their high-school preparation in mechanics and electricity and magnetism. Students who pass this test will have completed the "introductory sequence" by taking only 70; others may need to take the additional half courses of 71 and/or 72 (to be determined) to strengthen their background in these areas. Taking both 41 and 42 also satisfies the introductory sequence requirement.

Study Abroad: It is possible to study abroad and complete a physics major, although careful planning is necessary and the fall of the junior year is preferred. The department recommends that students consider programs where it will be possible to take physics while abroad and that students avoid being away during their senior year if at all possible. The Department of Physics and Astronomy is also sometimes able to provide opportunities to do summer research overseas in both disciplines as another means of providing international experiences.

Summer Research: The department encourages physics majors to gain practical experience doing research in physics during the summer. Students have opportunities to do sponsored summer research both on campus working with physics faculty, as well as with researchers at a variety of research institutions around the world. The Astronomy Program has a unique partnership with the Carnegie Observatories, based in Pasadena, which places about four Claremont students in research jobs each summer and which makes use of the Las Campanas Observatory in Chile. Students have done research internships at the National Institute of Standards, the National Renewable Energy Laboratory, Cornell University, Caltech, the Jet Propulsion Laboratory, the Smithsonian and other exceptional research institutions. Typical programs are 10 weeks long and include a stipend as well as some assistance with summer housing. The College has a strong record placing students in these programs both in the sophomore and junior years. In some cases, these projects are extended into senior thesis exercises.

Astronomy Courses

Astronomy (ASTR) courses satisfy Area 4 of the Breadth of Study Requirements.

1. Introductory Astronomy. *Mr. Penprase*. A non-calculus based survey course on modern astronomy with a focus on stellar, galactic and cosmic evolution. Particular emphasis will be placed on new and exciting observational results from space and ground-based observatories and how they shape our contemporary understanding of the formation and evolution of the universe and solar system. Includes a laboratory component with telescope. Every fall.

2. Introduction to Galaxies and Cosmology. *Mr. Choi*. A non-calculus introduction to cosmology. Topics will include our Milky Way galaxy, galaxy classification and evolution, historical perspectives on cosmology, an examination of the the large scale structrure of the universe and the history of the universe from the big bang to the present. Modern results and problems in cosmology will be examined. Next offered 2010-11.

6. Archeoastronomy and World Cosmology. *Mr. Penprase*. A survey of the development of astronomy and cosmology around the world.. Explores the role of astronomy and cosmology in organizing society and culture and in interpreting time and space. Additional topics include details of the cosmological systems of the ancient Mesoamerican, Greek and Chinese civilizations and a non-mathematical exploration of modern scientific cosmology. Next offered 2010-11.

51. Advanced Introductory Astronomy. *Mr. Penprase, Mr. Choi*. Provides an overview of the modern science of astrophysics. Theoretical and experimental evidence for the hot big bang, the formation of elements and the solar system and stellar evolution; exposition of the most pressing issues in the field of astronomy and astrophysics. Students design investigations and conduct a final project based on research in literature or observational studies in astronomy. Prerequisites: AP Physics or PHYS 41 or 70. Every spring.

62. Introduction to Astrophysics. *Staff*. Introduction to astrophysics with emphasis on topics of interest to students with a strong background in introductory physics. Topics include astronomical coordinate systems, celestial mechanics, solar physics, stellar structure, stellar evolution and cosmology. Prerequisite: PHYS 41 and 42, or PHYS 70. Every spring.

101. Observational Astronomy. *Ms. Esin*. A course emphasizing techniques of visual, photographic and electronic observations of astronomical objects. Discussion of infrared and radio astronomy, as well as space-based UV and X-ray astronomy. Includes preparation for and data reductions of observations. Also includes original astronomical observations using both the Brackett Observatory and the one-meter telescope at Table Mountain. Prerequisites: PHYS 41and 42, or 70, or 101; and ASTR 51 or 62. Offered jointly with Harvey Mudd and Joint Sciences. Each fall.

121. Cosmology and Extragalactic Astrophysics. *Mr. Penprase*. Examination of large-scale structure of the universe and evolution of the universe from Big Bang to present epoch. Topics include alternate cosmologies, dark matter, cosmic background radiation

and formation and evolution of galaxies and clusters of galaxies. Half-course. Prerequisites: PHYS 101, and ASTR 51 or 62, or permission of the instructor. Offered jointly with Harvey Mudd and Joint Sciences. Spring 2010; offered alternate years.

122. High-Energy Astrophysics. *Ms. Esin*. Analysis of the results of new ultraviolet, X-ray and gamma-ray observations and the astrophysical processes that produce high-energy photons. Topics include active galactic nuclei, black holes, neutron stars, supernova remnants and cosmic rays. Half-course. Prerequisites: PHYS 101, and ASTR 51 or 62, or permission of the instructor. Offered jointly with Harvey Mudd and Joint Sciences. Spring 2010; offered alternate years.

123. Stellar Structure and Evolution. *Mr. Choi*. A rigorous treatment of stellar atmospheres and radiative transfer. Topics include stellar energy generation, evolution on and away from the main sequence and the internal structures of stars and other self-gravitating objects. Prerequisites: PHYS 101, and ASTR 51 or 62, or permission of the instructor. Spring 2011; offered alternate years.

125. Galactic Astronomy. *Mr. Choi*. A detailed phenomenological investigation of galaxy structure, formation and evolution. We will explore galaxies as both aggregate stellar populations and signposts of cosmic evolution. The course will have a special focus on recent advances in the field. Half-course. Prerequisites: PHYS 101, and ASTR 51 or 62, or permission of the instructor. Offered jointly with Harvey Mudd and Joint Sciences. Spring 2011; offered alternate years.

199. Reading and Research. *Staff*. Prerequisite: permission of instructor. 99, lower-level; 199, advanced work. Course or half-course. May be repeated. Every semester. (Summer Reading and Research taken as 98/198.)

Physics Courses

Physics (PHYS) courses satisfy Area 4 of the Breadth of Study Requirements.

3. The Physics of Music. *Ms. Zook*. The physical principles underlying sound and its production, propagation and perception, with particular emphasis on the application of these principles to the production of musical sound with acoustic instruments. Lecture and laboratory. Intended for students without previous scientific background. Each fall.

17. Physics in Society: A Critical Analysis of Energy Policies. *Mr. Tanenbaum*. Analysis of solutions to the world's demand for energy. The physical principles behind energy production and the rationality of these approaches, including an exploration of feasibility, cost, efficiency, resource depletion, environmental waste products, environmental impact, global accessibility and risks of potentially catastrophic failures. Topics discussed will include coal, gas, fission, fusion, hydro, solar, biofuels and energy storage. Next offered 2010-11.

41, 42. General Physics with Laboratory. *Ms. Zook, Mr. Kwok, Mr. Tanenbaum*. Calculus-based introductory Physics for non-majors. 41 focuses on Newtonian Mechanics and Thermodynamics; 42 focuses on Electricity & Magnetism and Waves. Both courses highlight the physical principles behind modern instrumentation in geology, chemistry, biology and other scientific disciplines and biomedical applications are discussed. Prerequisites: completion of/or concurrent enrollment in MATH 30 for 41; MATH 31 and PHYS 41 for 42. 41, each spring; 42, each fall.

70. Spacetime, Quanta and Entropy with Laboratory. *Mr. Moore, Mr. Kwok*. Calculus-based introduction to principles of contemporary physics, designed especially for potential physics and astronomy majors. (Life-science students should take 41/42). Topics include conservation laws, special relativity, quantum physics and thermal physics, all viewed from a 21st-century perspective. Prerequisites: high school physics and completion or concurrent enrollment in MATH 30. Sophomores and above may enroll only with permission. Every fall.

71. Introductory Classical Mechanics. *Mr. Moore*. An introduction to classical mechanics, emphasizing the centrality of the fundamental conservation laws of Newtonian mechanics

and focusing on applying Newton's Laws of Motion and their consequences to standard physical systems such as the simple harmonic oscillator and planetary motion. Prerequisites: PHYS 70 and completion of/or concurrent enrollment in MATH 30. First years only; others only with permission. Half course. Each spring.

72. Introductory Electricity and Magnetism. *Mr. Moore*. An introduction to electricity, magnetism and waves, as summarized in Maxwell's equations of electricity and magnetism. Emphasizes the concepts of electric and magnetic fields and their interactions with charged particles, ultimately leading to the great synthesis of electricity, magnetism and light. Prerequisites: 70 and completion of/or concurrent enrollment in MATH30. First years only; others only with permission. Half-course. Each spring.

101. Atomic and Nuclear Physics with Laboratory. *Mr. Whitaker, Mr. Mawhorter.* Introduction to wave mechanics, spectra and structure of atoms, molecules and solids, nuclear physics and particle physics. Prerequisites: 41 and 42, or 70; and completion of/concurrent enrollment in MATH 32 or 107. Each fall.

125. Mechanics. *Mr. Tanenbaum*. The classical mechanics of Newton, Lagrange and Hamilton. The harmonic oscillator, the two-body problem, systems of oscillators and chaos. Heavy emphasis on problem solving. Prerequisites: PHYS 41 and 42, or 70; MATH 32 or 107; and completion of/or concurrent enrollment in MATH 60. Each spring.

128. Electronics with Laboratory. *Mr. Mawhorter.* Transistors and integrated circuits in a variety of applications, including operational amplifiers, basic digital circuits, analog/digital conversion and an introduction to microprocessors. Project required. Prerequisite: 41 and 42, or 70. Each spring.

142. Electricity and Magnetism. *Mr. Kwok*. Electrostatics, steady currents, magnetic fields, induction, Maxwell's equations, potential theory, material media and radiation theory. Prerequisites: 41 and 42, or 70; MATH 32 or 107; and completion of/concurrent enrollment in MATH 60. Each spring.

148. Computational Methods in Physics. *Ms. Zook*. Numerical and computational techniques used in modern physical sciences. Numerical methods for differentiation, integration and approximation and for the solution of differential equations and model systems. Examples from numerical modeling of both deterministic and random systems. Prerequisite: MATH 60. Next offered 2010-11.

160. Introduction to General Relativity. *Mr. Moore*. Development of Einstein's theory of general relativity from basic physical principles. Development of the mathematics of curved spacetime. Astrophysical applications, including spherically symmetric objects, black holes, cosmology and the creation and detection of gravitational waves. Prerequisite: 125. Spring 2010; offered alternate years.

165. Introduction to Physical Hydrodynamics. *Mr. Mitescu*. This course introduces the ideas underlying fluid mechanics using a fundamental physical approach. It discusses transport coefficients of fluids, the kinematics of continuous media, conservation laws and potential flow. Finally, it concludes with a treatment of vorticity and vortex dynamics, flow at low Reynolds numbers – including suspensions and porous media, boundary layers and hydrodynamic instabilities. Prerequisites: 125 and MATH 102. Fall 2009.

170. Quantum Mechanics. *Mr. Moore*. The Schroedinger equation, operator methods using Dirac notation, harmonic oscillator, angular momentum and other two- and three-dimensional systems with applications to atoms and molecules. Prerequisites: 101 and MATH 60. Every fall.

174. Contemporary Experimental Physics. *Ms. Zook, Mr. Mawhorter.* Experimental study of selected areas in physics and astronomy with emphasis on modern instrumentation and techniques. Discussion of techniques in error analysis and use of professional data presentation packages. Prerequisite: 101. Every spring.

175. Thermodynamics and Statistical Mechanics. *Mr. Whitaker.* Classical thermodynamics, kinetic theory and introduction to statistical mechanics. Prerequisites: 101 and MATH 60. Every spring.

180. Applied Mathematics for Physicists. *Mr. Mitescu.* Introduction to theory of functions of a complex variable. Evaluation of integrals by residues and other methods. Vector-derivative operations in curvilinear coordinates. Second-order linear differential equations: series and second solutions. Special properties of orthogonal functions: generating functions, recursion relations. Integral transforms. Prerequisites: 41 and 42, or 70; and MATH 102. Next offered 2010-11.

190. Senior Seminar. *Mr. Kwok, Mr. Whitaker.* Review and integration of major topics in physics. Reading, presentation and discussion of current research topics. In addition, each student formulates, executes and presents the results of his or her own individual research project, beginning with focused reading and presentations of pertinent research literature (from short communications to review articles), ending with a conference-style progress report. Senior majors or minors only. Each fall.

191E. Senior Thesis (Experimental). *Staff.* An experimental senior thesis consisting of a research project and paper in experimental, theoretical or computational physics. Full course. May be repeated once with the department's permission. Senior majors only. Every fall.

191L. Senior Thesis (Library). *Staff.* A library senior thesis consisting of a thorough and up-to-date literature survey and research paper on a topic of current interest in physics. Seniors whose senior thesis is based on a team project in a Harvey Mudd engineering or physics clinic should also select this thesis option. Half-course. May be repeated once with the department's permission. Each semester.

193. Senior Comprehensive Examination. *Staff.* Opportunity to demonstrate mastery of introductory and upper-division physics topics studied. P/NC grading only; no course credit. Senior majors only. Each fall.

199. Independent Study and Research. *Staff.* The following types of work, with faculty guidance, are available: 1) independent study of advanced subjects not treated in other courses of the department; and 2) individual or collaborative research for which funds and equipment are available. Prerequisite: permission of instructor. Course or half-course. Each semester.

Additional Courses Available at Harvey Mudd College

HM 80. Topics in Physics
HM 111. Theoretical Mechanics (equivalent to 125)
HM 116. Quantum Mechanics (equivalent to 170)
HM 117. Statistical Mechanics and Thermodynamics (equivalent to 175)
HM 151. Electromagnetic Field (equivalent to 142)
HM 154. Fields and Waves
HM 161. Topics in Quantum Theory
HM 162. Solid State Physics
HM 164. Particle Physics
HM 166. Geophysics
HM 168. Electrodynamics
HM 170. Computational Methods in Physics
HM 172. General Relativity and Cosmology
HM 174. Biophysics
HM 183, 184. Teaching Internship
HM 193, 194. Physics Clinic