Physics

The fascination of physics is that it is so fundamental: the continuing attempt to understand how things work. It combines observational and experimental grappling with nature to get the facts of behavior, with the creative synthesis of these facts into theories and laws of nature, often beautiful in their simplicity and universality.

Albert Einstein said, "They [the laws of theoretical physics] should form the basis from which a picture of all processes of nature can be derived by thoughtful deduction — and these include also the processes of life." He also said, "The deeper we search, the more we find there is to know, and as long as human life exists, I believe it will always be so."

More specifically, physics includes the study of the fundamental particles that make up nuclear particles, of electromagnetic, gravitational, atomic and nuclear forces, of energy, of light and heat, of electronics and the structure of materials, of the interiors of the earth and the stars.

Faculty and Facilities

Our faculty are here to teach and to do research. Several faculty members have research projects involving students. Two of our faculty members do theoretical work in particle physics and field theory while others are involved with numerous different experimental research fields; some of our faculty are involved in physics pedagogy.

Our classes are small; our upper-division and graduate classes usually have 10-15 students or less. Physics majors get to know each other very well. They develop friendships with peers, faculty, and staff, which extend well beyond graduation.

Our physics facilities underwent a multi-million dollar renovation. The renovation project substantially improves both our research and teaching capabilities. The department has well-equipped research laboratories with laminar flow hoods, evaporative and ion beam sputtering chambers, and high temperature ovens for thin film research. We have two medium-power lasers, which enhance our capabilities in modern optical studies, including Raman spectroscopy and nonlinear optics.

Four new research laboratories are also part of our current experimental efforts: the Radiation Measurements and Instrumentation Laboratory, the High Energy Physics Laboratory, the Semiconductor Characterization Laboratory, and the Astrophysics Laboratory. The High Energy Laboratory develops and constructs state-of-the-art solid-state charged particle detectors to be used in the D0 Project at Fermi National Laboratory (Fermilab). This has linked us to new frontier physics research areas, including studies of top quark properties and the search for the Higgs boson. The Semiconductor Laboratory is well equipped with both teaching and student research equipment, such as a pulsed NMR spectrometer, superconductivity experiment, temperature-dependent measurement of resistivity, and conduction phenomena determination of semiconductor band gap. Two new major pieces of equipment have been added to our condensed matter physics research: an X-ray fluorescence spectrometer that is capable of sub *ppm* resolution and a Fourier Transform Infrared spectrometer (FTIR) that permits analysis of spectra in the mid-infrared region. We also have an argon ion laser (tunable) with a 400 megawatt output, a three-stage high temperature furnace, and a fume hood providing a sample preparation chamber. This allows us to make many important measurements of condensed matter properties such as resistivity, conductivity, mobility, charge concentration, activation energy, the charge sign of majority carriers, and photoconductivity. It leads us to material science

College of Science and Mathematics

Department of Physics
Vanvilai Katkanant, *Chair*
Deidre Fields, *Administrative Support Coordinator*
McLane Hall, Room 173
(559) 278-2371
FAX: (559) 278-7741
http://physics.csufresno.edu/

B.S. in Physics

B.A. in Natural Science Teaching Credential

M.S. in Physics

Minor in Astronomy

Minor in Medical Physics

Minor in Physics

Minor in Physical Science

technologies and novel semiconductors used in solar cell applications. The Astrophysics Laboratory is loaded with powerful new computing equipment, all available to students. It is used for image processing and remote observatory operations. Graduate students can participate in astrophysics research. They use both ground-based telescopes and space observatories (including the *Hubble Space Telescope*, *Chandra X-ray Observatory*, and other NASA spacecraft.)

We have upgraded instrumentation in our existing Radiation Laboratory and we have begun a new program of research in biomedical physics. In general, the field is subdivided into four subspecialties: nuclear medicine, diagnostic radiology (use of X-rays, MRI, ultrasound, etc.), radiation therapy (the use of radioactive materials produced by accelerators for the treatment of cancer and other diseases), and radiation biology. With the establishment of affiliations with local area medical centers, research opportunities in this field will open up for our students.

We have received a grant from the National Institute of Mental Health (NIH/NIMH) to initiate one of the first medical physics/neuroimaging undergraduate programs in the nation. Students enrolling in this special degree program will get a chance to intern at the end of their junior year in the

finest state-of-the-art laboratories across the nation. Our department has a collaboration with the VA Medical Center, where students are provided with hands-on instruction on MR scanners and other imaging equipment. The curriculum ranges from courses in MRI/MRS, X-ray imaging, nuclear medicine, and neuroimaging to courses in radiation health physics. This program is designed to provide a solid foundation in physics, biology, and mathematics so that students can tackle the challenges of an interdisciplinary program of graduate instruction in the broad field of neurosciences. The program also aims to serve as a feeder program to graduate schools across the nation.

The Downing Planetarium, operated by the Physics Department, was completed in the spring of 2000. It has proven highly successful, with more than 100,000 visitors since opening. The planetarium features a computer controlled Minolta MS-8 star projector and a main theater with 74 reclining seats under a 30-foot dome. The facility presents multi-media shows on a daily basis. Physics students have the opportunity to participate in presenting the shows and to assist in planetarium operation.

Adjacent to the planetarium is a new campus observatory equipped with a 16-inch Schmidt-Cassegrain telescope, CCD camera, and adaptive optics system. This observatory is being used for classes and for student research projects. A second observatory with a more advanced 16-inch telescope is being planned for a dark site in the Sierra Nevada mountains. This telescope will be remotely controlled from campus, and students will be able to download images from it over the Internet without having to go to the telescope site. Eventually, the observatory will be able to function as a totally autonomous robot, able to carry out a student's program of observations and close itself down at the onset of bad weather.

Career Opportunities

Approximately half of our bachelor's and master's degree graduates have gone directly into graduate school at various institutions, pursuing master's or doctoral degrees in physics or related fields. The other half have found employment in teaching, in industry, in government, and in the medical professions. We have also observed a recent increase in the demand for high school physics teachers.

Physics graduates have the versatility, knowledge, and analytical skills necessary to adapt quickly to the opportunities which arise in the dynamic world of modern science and high technology. Our graduates report interesting, exciting careers with increasing levels of responsibility and satisfaction.

Faculty

Vanvilai Katkanant, *Chair*

Raymond Hall,
Undergraduate Adviser

Douglas Singleton, *Graduate Coordinator*

Amir Huda,
Premedical and Preoptometry Adviser

Steven J. White,
Downing Planetarium Director

Manfred Bucher
Brandt Kehoe
Gerardo Munoz
Frederick Ringwald
Michael J. Zender

Bachelor of Science in Physics

The B.S. in Physics offers preparation appropriate to employment in government and industry involving a range of activities from laboratory work to technical sales. It also offers appropriate background preparation for graduate study in physics and a large number of other fields. With an appropriate choice of electives, it provides a very strong premedical, predental, or preoptometry program.

Beyond professional goals, the study of physics provides a deep understanding of fundamental processes which underlie our physical world and fosters methods of inquiry which promote intelligent analysis generally.

Bachelor of Science Degree Requirements

Physics Major *Units*

Physics requirements 47
(see *note 1*)
Physics core ..... (30)
PHYS 4A, 4AL, 4B, 4BL, 4C, 102, 104, 105A, 105B, 107A, 110
Upper-division electives ..... (17)
Includes courses in physics and, with approval, in related fields. Students planning to pursue graduate study in physics are strongly encouraged to take PHYS 107B, 115, 130, 140, 162, and 170A (see *note 2*)

Additional requirements 27-29*
(see *notes 1 and 3*)
MATH 75, 76, 77, 81;
CHEM 1A, 1B ..... (25)
Plus one of the following
IT 52 or CSCI 15 or
CSCI 40 or ECE 70 ..... (2-4)

General Education requirements ... 45**

Electives 0-1

Total units 120*

* The 120 unit total assumes students will select either IT 52, CSCI 15, or ECE 70 for this area.

** There are 51 units required for General Education. Of these 51 required units, 6 units will be satisfied by the following two courses in additional requirements: 3 units of CHEM 1A in G.E. Breadth B1 and 3 units of MATH 75 in G.E. Foundation B4.

Advising Notes

1. ***CR/NC*** grading is not permitted in the physics major. Additional requirements, however, may be taken ***CR/NC*** (see *Credit/No Credit Grading).*
2. Courses outside the Department of Physics may be substituted for physics upper-division electives with prior approval of the department chair.
3. Students should be sure to take sufficient upper-division units in their General Education courses and electives to satisfy the university requirement of 40 upper-division units. It is important to fulfill the upper-division writing skills requirement by exam or ***W*** class after completing 60 units for which a student may request 1 unit of credit.

Suggested Sequence of Courses for the B.S. in Physics

The list below is a suggested schedule of courses for the major for students planning to complete the suggested pregraduate study sequence in four years.

In addition to the specific courses listed below, General Education requirements and electives should be included to bring the average total of units to 15 per semester. A minimum total of 120 units must be completed for the Bachelor of Science degree. (See *Degree Requirements*.)

1st Year: PHYS 4A, 4AL; CHEM 1A, 1B; MATH 75, 76; Computer Programming

2nd Year: PHYS 4B, 4BL, 4C; MATH 77, 81
3rd Year: PHYS 102, 104, 105A, 105B, 110, 150, 170A
4th Year: PHYS 107A, 107B, 115, 130, 140, 162; plus upper-division electives

Physics Minor

	Units
PHYS 4A, 4AL, 4B, 4BL, 4C	11
PHYS 102	3
Other upper-division physics	6
Total units	**20**

Note: The Physics Minor also requires a 2.0 GPA and 6 upper-division units in residence.

Bachelor of Arts in Natural Sciences

Physics Option

The B.A. in Natural Sciences is designed primarily to meet the needs of students interested in pursuing a teaching career in the sciences at the secondary level. Students interested in satisfying the waiver program in the natural sciences should consult an appropriate adviser early in their academic program. Contact either the Department of Physics or the Office of the Dean, College of Science and Mathematics.

The degree is also a suitable choice for students with a general interest in physics and interest in pursuing a career in law, medicine, dentistry, optometry, and other areas for which the breadth of scientific coverage of this degree is advantageous.

A full description of the degree, including all of the emphases available, can be found in the *Natural Sciences Interdisciplinary Courses* section in this catalog. For more information, please contact David Andrews, B.A. in Natural Science coordinator and science credential adviser, at (559) 278-2412. The B.A. in Natural Sciences with the Physics Emphasis is as follows:

Bachelor of Arts Degree Requirements

Natural Sciences Major	*Units*
Core requirements	**37**
Biology	(12)
BIOSC 1A, 1B, 130	
Chemistry	(10)
CHEM 1A, 1B	
Geology[1]	(8)
GEOL 1 and 3 (or 15)[1], 168	
Natural Science	(3)
NSCI 106	
Physical Science	(4)
PSCI 21	
Physics Option	**44**
CHEM 128A	(3)
PSCI 168	(3)
MATH 75, 76, 77, 81, 90	(16)
PHYS 4A, 4AL, 4B, 4BL, 4C	(11)
PHYS 102, 105A, 107A, 130	(11)
General Education requirements[2,3]	**51**
Total units	**120**

Advising Notes for the Natural Sciences Major

1. GEOL 15 is part of the Humans and the Natural Environment Cluster. See the *Natural Sciences Interdisciplinary Courses* section in this catalog. GEOL 15 is equivalent to GEOL 1 and 3.
2. Of the 51 General Education units, 12 units may be satisfied as follows: CHEM 1A (3 units), BIOSC 1A (3 units), GEOL 168 (3 units), and MATH 75 (3 units). Consult your major adviser for details.
3. Students should be sure to take sufficient upper-division units in their General Education courses and electives to satisfy the graduation requirements of 40 upper-division units and upper-division writing skills.

Waiver Program for the Single Subject Credential in the Sciences

Students interested in satisfying the waiver program in the Natural Sciences should consult an appropriate adviser early in their academic program.

Astronomy Minor

	Units
PHYS 4A, 4AL, 4B, 4BL, 4C	11
PSCI 21	4
PHYS 150	3
Remaining requirement	3
Choose one course from GEOL 150T (Planetary Science), PHYS 110, 145, 175T (Computational Physics, Observational Astronomy), or 190 by approval	
Total units	**21**

Note: The astronomy minor also requires a 2.0 GPA and 6 upper-division units in residence.

Medical Physics Minor

	Units
PHYS 4A, 4AL, 4B, 4BL, 4C	11
PHYS 130	2
PHYS 136	3
Remaining requirement	4
Choose one course from PHYS 175T (Intro to MRI/MRS, Nuclear Medicine, or Radiation Biology)	
Total units	**20**

Note: The medical physics minor also requires a 2.0 GPA and 6 upper-division units in residence.

Physical Science Minor

The Physical Science Minor offers an opportunity for both nonscience and science majors to diversify into important and interesting fields. It consists of 21 units of courses selected according to one of the patterns listed in the copy that follows:

	Units
A. CHEM 3A and 3B	7*
PHYS 2A and 2B	8*
Upper-division electives	6**
	21
B. CHEM 10	3
PHYS 2A and 2B	8*
GEOL 1	4
Upper-division electives	6**
	21
C. CHEM 3A and 3B	7*
PHYS 10	4
GEOL 1	4
Upper-division electives	6**
	21

For chemistry, geology or physics majors, all courses must be outside the major department. The revised program must be approved by the chair of the major department.

Note: The Physical Science Minor also requires a 2.0 GPA and 6 upper-division units in residence.

* CHEM 1A may be substituted for CHEM 3A, and CHEM 1B may be substituted for CHEM 3B. PHYS 4A and 4AL may be substituted for PHYS 2A, and PHYS 4B and 4BL may be substituted for PHYS 2B.

** The upper-division electives may be any upper-division courses for which the student is qualified, from the three departments. Courses with very few prerequisites are CHEM 139; GEOL 105, 114, 154, 168, 169; PHYS 100, 145; PSCI 106, 131, 168.

Graduate Program

The Department of Physics offers graduate instruction and research leading to the Master of Science degree.

For general information, read the *Graduate Studies* section in this catalog, and in particular, the sections on *Admission to Graduate Standing, Advancement to Candidacy, and Program Requirements*. The minimum entrance requirements are a GPA of 2.5 over the last 60 units, satisfactory scores on the GRE General Examination, and good references. Although the GRE scores are not the only, or most important, criteria used in the admission process, we generally look for scores above 600 on the quantitative portion of the exam or for a total above 1,000 on the combined quantitative and verbal portions. The GRE General Examination must be taken before applying for admission.

It is important to achieve classified standing quickly, before completion of 10 units. The next step is advancement to candidacy, after completion of at least 9 units of graduate study with a minimum GPA of 3.0 and satisfaction of the graduate writing proficiency requirement by taking PHYS 290. The graduate writing requirement may be fulfilled by taking PHYS 290 and passing the writing proficiency component of the course. Please contact the graduate coordinator for more information. Advancement also requires a scoring at or above the 25th percentile on the Advanced Physics GRE Subject Examination.

Teaching assistantships are usually available, as is general financial aid. For some forms of financial aid, application must be completed before the end of February.

For specific questions, consult the chair of the department or the graduate adviser/coordinator.

Master of Science in Physics

The objective of our M.S. program is to build a firm basis for subsequent Ph.D. study in physics or in related fields, for positions in industry, and for teaching at the community college level. We offer a broad-based academic program with the opportunity for specialized theoretical or experimental research. Students completing degrees have successfully pursued all three of these career goals — with roughly equal numbers going to doctoral programs and industry, and a smaller number directly into teaching.

Areas of research in which our faculty are active include physics pedagogy, condensed matter theory and experiment, characterization of materials properties (amorphous semiconductors), dipolar magnetism, Fullerene research, laser Raman spectroscopy, radiation medical physics, classical and quantum field theory, and general relativity. Faculty also study forces and interaction of fundamental constituents of matter with experiments using the world's most powerful particle accelerator at Fermi National Laboratory. Astronomy research includes observations of cataclysmic variables, black holes, and extrasolar planets. It is done with the most powerful instruments available today, including the *Hubble Space Telescope*, the *Chandra X-ray Observatory*, other NASA spacecraft, and the Keck I telescope, the largest on Earth, as well as many other telescopes around the world.

Under the direction of the graduate adviser and the graduate faculty, a coherent program, directed toward the student's goal in graduate study and designed within the framework outlined in the copy that follows, is prepared and submitted to the department. There is a standard core of classical mechanics (PHYS 203), classical electrodynamics (PHYS 220A, B) and quantum mechanics (PHYS 222A, B) which is strongly recommended for students planning to pursue further graduate study — and, at least in part, for all students. Other courses, both from within and from outside the department, can be used to complete the 30 unit master's program. A culminating experience, consisting of either a thesis (PHYS 299) or a project (PHYS 298) plus a competency examination, is required.

Undergraduate education equivalent to a physics major at California State University, Fresno is necessary for admission. Note the other requirements under *Graduate Program.*

	Units
Physics graduate courses	**21**
PHYS 290 (minimum 3 units); PHYS 298 or 299 (minimum 3 units)	(6)
Additional graduate courses in physics	(15)
Students planning further graduate study should include PHYS 203, 220A-B, 222A, and 222B.	
Upper-division or graduate electives in physics or related fields	**9**
Total	**30**

COURSES

Physics (PHYS)

2A. General Physics (4)
Prerequisite: G.E. Foundation B4. Topics and concepts in Newtonian mechanics of point particles and rigid bodies, energy, properties of fluids, heat and thermodynamics, waves and sound. G.E. Breadth B1. (3 lecture, 3 lab hours) (CAN PHYS 2)

2B. General Physics (4)
Prerequisite: PHYS 2A. Topics and concepts in light, electricity, magnetism, atomic structure, relativity, quantum nature of light and matter, nuclear structure and radiation. (3 lecture, 3 lab hours) (CAN PHYS 4)

4A. Mechanics and Wave Motion (3)
Prerequisite: G.E. Foundation B4; MATH 76 (may be taken concurrently). Topics in classical Newtonian mechanics including linear and circular motion, energy, linear and angular momentum, systems of particles; rigid body motion; fluids; gravity; wave motion; and sound. G.E. Breadth B1 when taken with PHYS 4AL.

4AL. Laboratory in Mechanics and Wave Motion (1)
Corequisite: PHYS 4A; prerequisite: G.E. Foundation B4. Introduction to laboratory methods. Experiments in mechanics, waves, and sound. G.E. Breadth B1 when taken with PHYS 4A. (3 lab hours)

4B. Electricity, Magnetism and Heat (3)
Prerequisites: PHYS 4A; MATH 77 (may be taken concurrently). Topics in classical physics including heat and thermodynamics, electrostatics, electric fields and potential, currents and AC and DC electric circuits, magnetic fields, electromagnetic induction.

4BL. Laboratory in Electricity, Magnetism, and Heat (1)
Corequisite: PHYS 4B. Experiments in electricity, magnetism, heat, and thermodynamics. (3 lab hours)

4C. Light and Modern Physics (3)
Prerequisites: PHYS 4B, MATH 77. Maxwell's Equations, geometrical optics; electromagnetic radiation; physical optics; introduction to special relativity; quantum physics; and the physics of atoms, nuclei, and the solid state.

10. Conceptual Physics (4)
Prerequisites: G.E. Foundation B4 (except for those with declared majors in the College of Science and Mathematics). Basic ideas of physics and their relationship to the everyday environment. Physical phenomena, misconceptions, terminology, scientific method, and metric system. Memorable demonstrations in lectures; household-related experiments in the lab. G.E. Breadth B1. (3 lecture, 2 lab hours)

90. Directed Study (1-2; max total 3)
Prerequisite: any university-level physics or physical science course. Individually arranged course of study in some limited area of physics, either to remove a deficiency or to investigate in more depth. (1-2 hours to be arranged)

100. Concepts of Quantum Physics (3)
Prerequisites: G.E. Foundation and Breadth Area B. Key discoveries in quantum physics and conceptual development of quantum theory. Lecture demonstration of experiments, graphical visualization of theory, and hi-tech applications. G.E. Integration IB. (3 lecture hours)

102. Modern Physics (3)
Prerequisite: PHYS 4C; MATH 81 (may be taken concurrently). Fundamental concepts of atomic and nuclear structure, transitions and radiation. Includes discussions of relativistic mechanics, quantum mechanics, solid state physics. Special topics as they pertain to modern developments in physics, engineering, and chemistry.

104. Experimental Techniques in Condensed Matter Physics (4)
Prerequisite: PHYS 4C. Shop techniques and safety instructions. Basic concepts in condensed matter physics. Measurements of conductivity, energy gap in semiconductors, drift mobility, Hall coefficients, photoconductivity, magnetic susceptibilities, exciton spectra, dielectric loss. Experience in X-ray diffraction, vacuum technology, thin-film deposition, and low temperature techniques. (1 lecture, 9 lab hours)

105A-B. Analytical Mechanics (3-3)
Prerequisite: PHYS 4C; MATH 81 (may be taken concurrently). (A) Analytical and vector treatment of the fundamental principles of statics, kinematics, and dynamics. (B) Prerequisite: PHYS 105A. Advanced dynamics; harmonic motion, central force fields, and Lagrange's equations.

107A-B. Intermediate Electricity and Magnetism (3-3)
(A) Prerequisites: PHYS 105A, MATH 81. Mathematical analysis of electrostatics and magnetostatics, Gauss' law, solutions of Laplace's equation, images, theory of conduction, magnetic potentials. (B) Prerequisite: PHYS 107A. Motion of ions in electric and magnetic fields, electromagnetic induction, Maxwell's equations and wave propagation, electron theory, and magnetic properties.

110. Physical Optics (3)
Prerequisites: PHYS 4C, MATH 81. Theory of optical phenomena; wave theory of light with applications to optical instruments; interference and diffraction phenomena, dispersion, polarization, coherence, and laser phenomena. Practical experience in using lasers and optical instruments. (2 lecture, 3 lab hours)

115. Quantum Mechanics (3)
Prerequisites: PHYS 102, 105A, 170A (may be taken concurrently), MATH 81. Historical background, postulates, meaning, and methods of quantum mechanics; applications to atomic phenomena.

130. Advanced Laboratory (2)
Prerequisite: PHYS 102. Advanced experiments in atomic and nuclear physics. Radiation safety. Gamma ray, X-ray, and particle detection and spectroscopy. X-ray fluorescence analysis, Mossbauer, coincidence, Compton scattering and radiation attenuation experiments. Statistics, error analysis. Projects. (6 lab hours)

136. Radiation Physics (3)
Prerequisite: PHYS 102. The interaction of radiation with matter: photoelectric, Compton and pair production processes, neutron and charged particle interactions, linear energy transfer, quality factor, attenuation coefficients, shielding. Biological effects, RBE, internal dose, permissible exposures, beneficial application. Instrumentation.

140. Thermodynamics and Kinetic Theory (3)
Prerequisite: PHYS 102, MATH 81. Fundamental concepts and laws of classical thermodynamics. Rudiments of kinetic theory and statistical thermodynamics with application to physical and chemical systems.

145. Geophysics (3)
Prerequisites: PHYS 2A, 2B or 4A, MATH 75. Basic principles of physics applied to the solution of geological problems, rotation and figure of the earth, the gravity field, seismology and the earth's interior, geomagnetism, and the thermal history of the earth.

150. Astrophysics (3)
Prerequisites: MATH 75 and PHYS 2A, 2B or PHYS 4A, 4B and 4C. Introduction to celestial mechanics, spectral classification, stellar atmospheres and interiors, star formation and evolution, variable stars, neutron stars, pulsars, black holes, the nature of galaxies, and the expansion of the universe.

162. Condensed Matter Physics (3)
Prerequisites: PHYS 102, or CHEM 110B and permission of instructor. Classification of solids; crystalline state and lattice vibrations; properties of metallic lattices and dielectrics; magnetic properties of solids; free electron theory and band theory of metals; semiconductors; imperfections.

170A. Mathematical Physics (3)
Prerequisite: PHYS 4C, MATH 81. Application of mathematical methods to the solution of problems in physics.

175T. Topics in Contemporary Physics (1-4; max total 12)
Designed to provide students with special work in such areas of physics as biophysics, modern optics, plasmas, high energy physics, solid state, chaos theory, nuclear structure, astrophysics, low temperature phenomena. Some topics may have labs.

180. Seminar in Physics (1; max total 3)
Prerequisite: senior or graduate physics major or permission of department chair.

190. Independent Study (1-3; max total 6)
See *Academic Placement — Independent Study*. Approved for ***RP*** grading.

GRADUATE COURSES

(See *Course Numbering System*.)

Physics (PHYS)

203. Classical Mechanics (4)
Prerequisites: PHYS 105B, 170A. Advanced treatment of classical analytical mechanics including Lagrange's and Hamilton's formulation of the laws of motion, special relativity, small oscillation theory, hydrodynamics.

220A-B. Advanced Electricity and Magnetism (3-3)
Prerequisites: PHYS 107B, 170A. Electromagnetic theory and its applications; electrostatics, boundary-value problems in electrostatics, dielectrics, multipoles, magnetostatics, Maxwell's equations, electromagnetic radiation, optical properties of materials, wave guides and resonant cavities.

222A. Quantum Mechanics I (3)
Prerequisite: PHYS 115, 170A. Quantum Dynamics: representations and pictures, path integrals, evolution operator, propagators. Angular Momentum: orbital and spin, addition. Perturbation Theory: time-independent and time-dependent problems, sudden and adiabatic approximations. Scattering: Lippman-Schwinger equations, scattering matrix, Born approximation, partial waves.

222B. Quantum Mechanics II (3)
Prerequisite: PHYS 222A. Identical Particles: fermions and bosons, second quantization. Electromagnetic Fields: radiation field, photons, coherent states, vacuum state and Casimir effect, interactions with charged particles. Relativistic Quantum Mechanics: Klein-Gordon and Dirac equations, relativistic hydrogen atom, perturbation theory and Feynman diagrams.

262. Advanced Condensed Matter Physics (3)
Prerequisites: PHYS 115, 162, 170A. Binding and crystal structure, crystal electron theories, elementary excitations, transport theories, crystal defects, superconductivity.

270. Advanced Mathematical Physics (3)
Prerequisite: PHYS 170A. Group theory, including continuous (Lie) groups, Lie algebras, and an introduction to the theory of representations, Green's functions and their applications to physical problems, and integral equations including diagrammatic methods of solution.

272. General Relativity (3)
Prerequisite: PHYS 203. The principle of equivalence, tensor calculus in curved spacetimes, the Einstein-Hilbert equations, the Schwarzschild solution, tests of general relativity, gravitational radiation, introduction to cosmology.

275T. Topics in Contemporary Physics (1-3; max total 6)
Advanced topics in such areas as modern optics, plasma physics, high energy physics, astrophysics, nuclear physics, biophysics. Some topics may have labs.

290. Independent Study (1-3; max total 6)
See *Academic Placement — Independent Study*. Approved for ***RP*** grading.

298. Project (2-6; max total 6)
Prerequisite: permission of instructor. Scholarly investigation by the advanced graduate student as a culminating experience for the master's degree, including a written project report and an oral defense, and followed by a competency exam. Approved for ***RP*** grading.

299. Thesis (2-6; max total 6)
Prerequisite: See *Criteria for Thesis and Project*. Preparation, completion, and submission of an acceptable thesis for the master's degree. Approved for ***RP*** grading.

PHYSICAL SCIENCE COURSES

Physical Science (PSCI)

ASTRONOMY

21. Elementary Astronomy (4)
Prerequisite: G.E. Foundation B4 (except for those with declared majors in the College of Science and Mathematics). Recommended: second-year high school algebra. Concepts, theories, important physical principles, and history of astronomy. Stellar properties, distances, and evolution. Three field trips for observing with telescopes. G.E. Breadth B1. (3 lecture, 2 lab hours)

OTHER

106. History of Physical Science (3)
The development of our understanding of the physical world from ancient times to the 20th century with an emphasis on astronomy, mechanics, thermodynamics, and the nature of matter. An exploration of the evolution of ideas.

131. Concepts of Classical Physics from Babylon to Maxwell (3)
Prerequisites: G.E. Foundation and Breadth Area B. Concepts, theories, and laws of classical physics. Mathematics, astronomy, mechanics, light, electricity, magnetism, thermodynamics, chemistry, and the atom. G.E. Integration IB.

168. Energy and the Environment (3)
Prerequisites: G.E. Foundation and Breadth Area B. Analysis of energy crisis; introduction to various forms of energy, energy conversion processes and environmental effects; present energy supply and energy projections; future energy demands and ways of evaluating alternatives. G.E. Integration IB. (3 lecture hours)

180T. Topics in Physical Science (1-3; max total 9)
Detailed discussion of special topics within the realm of physical science.

IN-SERVICE COURSES

(See *Course Numbering System*.)

Physical Science (PSCI)

305. Physical Science for Secondary School Teachers (3; max total 6 in any one field)
Prerequisites: secondary credential and two years of teaching experience. Objectives, content, and instructional materials for the physical sciences; fundamental principles and recent developments. Emphasis may be on chemistry, geology, or physics.

350. Physical Science for Elementary School Teachers (3-6; max total 6 in any one field)
Maximum total credit 12 units; not more than 6 units in one field. Prerequisite: elementary credential. Selection of source materials and aids available for illustration of fundamental concepts and principles in physical science; laboratory work in construction, operation, and use of demonstrations and experiments in the elementary school.