Physics and Astronomy

College of Natural Sciences and Mathematics

Bachelor of Arts• Bachelor of Science
Minor • Certificate
Subject Matter Program (Pre-Credential Preparation)

PROGRAM DESCRIPTION

Physics is the most fundamental science and underlies our understanding of nearly all areas of science and technology. In a broad sense, physics is concerned with the study of energy, space, and matter, and with the interactions between matter—and the laws that govern these interactions. More specifically, physicists study mechanics, heat, light, electric and magnetic fields, gravitation, relativity, atomic and nuclear physics, and condensed matter physics.

The Department of Physics and Astronomy at Sacramento State offers three degree programs: the BA in Physics, the BS in Physics, and the BA in Physical Science, and one program for a Single Subject Teaching Credential in Physics; the Department also offers Minor programs in Physics and Astronomy. The BS degree is recommended for students seeking a career in Physics or planning to pursue a graduate degree. The BA degree is recommended for students who are interested in teaching Physics in high school or who want a liberal arts education with an emphasis in Physics. Physics majors are encouraged to take additional mathematics and to develop skills in the use of computers.

Approximately 50 percent of the graduating physics majors from Sacramento State continue on to graduate school earning advanced degrees in Physics, Mathematics, Engineering, Environmental Science, Medicine or Business. Another 40 percent find job opportunities in industrial and government laboratories or agencies. The remaining 10 percent obtain their teaching credential.

Special Features

- In addition to providing a broad academic background and facility in analytic thinking, the study of physics fosters and emphasizes independent study experiences. Physics students at Sacramento State typically spend a year or two working on the design and building of scientific apparatus, assisting a faculty member in a research project, or doing independent study on a topic of special interest to them. These independent projects not only provide a vehicle for applying material learned in class and give students experience in electronics, measurement systems, computers, and machine shop work, but also teach students to work and think on their own. Faculty in the Department have been active in research in acoustics, atomic physics, astrophysics, energy, holography, nuclear physics, optics, quantum mechanics, relativity and solid state physics.
- An advising system has been established by the Department of Physics and Astronomy to help students plan their schedules each semester, to discuss independent project possibilities, and to provide career and current job information. Because of the large number of sequential courses in the degree programs, the Department requires that each student contact his/her advisor before registering for classes each semester. Any student without an advisor should contact Professor Gary Shoemaker in Sequoia Hall 230, or call (916) 278-6518.

Career Possibilities

Research Physicist or Applied Physicist in: Acoustics • Atmospheric Physics • Astrophysics • Astronomy • Atomic and Molecular Physics • Electricity and Magnetism • Electronic Instrumentation • Energy Conservation • Geophysics • Health Physics • Heat • Light • Mechanics • Medical Imaging • Nuclear Medicine • Nuclear Physics • Solar Energy • Solid State Physics • Scientific Computing • Engineer • Science Educator • Technical Writer

Faculty

William DeGraffenreid, Frank Hicks, Sukhbir Mahajan, Zolili Ndlela, Hossein Partovi, Jim Phelps, Vassili Sergan, Michael Shea, Gary Shoemaker, John Stevens, Lynn Tashiro, Christopher Taylor, Paul Peter Urone

Contact Information

Gary Shoemaker, Department Chair
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UNDERGRADUATE PROGRAMS

Requirements • Bachelor of Arts Degree - Physics

Units required for Major: 66
Minimum total units required for the BA: 120

Courses in parentheses are prerequisites.

A. Required Lower Division Courses (37 units)

(5)	CHEM 1A	General Chemistry I (High school algebra [two years] and high school chemistry; or equivalent)
(5)	CHEM 1B	General Chemistry II (CHEM 1A with a passing grade of "C" or better)
(4)	MATH 30	Calculus I (MATH 29 or four years of high school mathematics which includes two years of algebra, one year of geometry, and one year of mathematical analysis; completion of ELM requirement and Pre-Calculus Diagnostic Test)
(4)	MATH 31	Calculus II (MATH 30 or appropriate high school based AP credit)
(4)	MATH 32	Calculus III (MATH 31)
(3)	MATH 45	Differential Equations for Science and Engineering (MATH 31)
(4)	PHYS 11A	General Physics: Mechanics (MATH 30, MATH 31; or equivalent certificated high school courses. MATH 31 may be taken concurrently)
(4)	PHYS 11B	General Physics: Heat, Light, Sound (MATH 31, PHYS 11A)
(4)	PHYS 11C	General Physics: Electricity and Magnetism, Modern Physics (MATH 31, PHYS 11A)

B. Required Upper Division Courses (22-23 units)

(3)	PHYS 105	Mathematical Methods in Physics (MATH 32; PHYS 11A, PHYS 11B, PHYS 11C or PHYS 5A, PHYS 5B)
(3)	PHYS 106	Introduction to Modern Physics (MATH 31; PHYS 11A, PHYS 11B, PHYS 11C or PHYS 5A, PHYS 5B)
(3)	PHYS 110	Classical Mechanics (MATH 45, PHYS 11C, PHYS 105)
(4)	PHYS 115	Electronics and Instrumentation (PHYS 11C or PHYS 5B with instructor permission) **OR**
(3)	PHYS 145	Optics (MATH 45, PHYS 11A, PHYS 11B, PHYS 11C)
(3)	PHYS 124	Thermodynamics and Statistical Mechanics (MATH 45, PHYS 11A, PHYS 11B, PHYS 11C)
(3)	PHYS 135	Electricity and Magnetism (MATH 45, PHYS 11C, PHYS 105)
(2)	PHYS 175	Advanced Physics Laboratory (12 units of upper division physics including PHYS 106 and either PHYS 115 or PHYS 145 and satisfaction of the Advanced Writing requirement)
(2)	PHYS 191	Senior Project (Department Chair permission)

C. Elective Upper Division Requirements (6 units)

Six elective units in Physics selected in consultation with an advisor.

(3)	PHYS 116	Advanced Electronics and Instrumentation (PHYS 115)
(3)	PHYS 130	Acoustics (MATH 45, PHYS 11A, PHYS 11B, PHYS 11C)
(3)	PHYS 142	Applied Solid State Physics (MATH 45, PHYS 106)
	PHYS 196 series course	Experimental Offerings in Physics (1-3 units per semester; 4 unit maximum)
	PHYS 198	Co-curricular Activities (1-3 units per semester; 4 unit maximum)
	PHYS 199	Special Problems (1-3 units per semester; 4 unit maximum)

And whichever of the courses below not previously used to fulfill the upper division requirement:

(4)	PHYS 115	Electronics and Instrumentation (PHYS 11C or PHYS 5B with instructor permission) **OR**
(3)	PHYS 145	Optics (MATH 45, PHYS 11A, PHYS 11B, PHYS 11C)

Requirements • Bachelor of Science Degree - Physics

Units required for Major: 75
Minimum total units required for the BS: 120

Courses in parentheses are prerequisites.

A. Required Lower Division Courses (37 units)

Same as Section A for BA in Physics.

B. Required Upper Division Courses (34-35 units)

Same as **Section B** for BA in Physics plus the following:

(3)	PHYS 136	Electrodynamics of Waves, Radiation, and Materials (PHYS 135)
(3)	PHYS 150	Quantum Mechanics (MATH 45, PHYS 106, PHYS 110)
(3)	PHYS 151	Advanced Modern Physics (PHYS 150)
(3)	PHYS 156	Classical and Statistical Mechanics (PHYS 110 and PHYS 124)

C. Elective Upper Division Requirements (3 units)

Six elective units in Physics selected from the following in consultation with an advisor:

(3)	PHYS 116	Advanced Electronics and Instrumentation (PHYS 115)
(3)	PHYS 130	Acoustics (MATH 45, PHYS 11A, PHYS 11B, PHYS 11C)
(3)	PHYS 142	Applied Solid State Physics (MATH 45, PHYS 106)
(3)	PHYS 162	Computational Physics (two semesters of calculus: PHYS 5A and PHYS 5B or two of the following: (PHYS 11A, PHYS 11B, or PHYS 11C. Ability to program in a language such as BASIC, PASCAL, FORTRAN or C)
	PHYS 196 series course	Experimental Offerings in Physics (1-3 units per semester; 4 unit maximum)
	PHYS 198	Co-curricular Activities (1-3 units per semester; 4 unit maximum)
	PHYS 199	Special Problems (1-3 units per semester; 4 unit maximum)

And whichever of the courses below not previously used to fulfill the upper division requirement:

(4)	PHYS 115	Electronics and Instrumentation (PHYS 11C or PHYS 5B) **OR**
(3)	PHYS 145	Optics (MATH 45, PHYS 11A, PHYS 11B, PHYS 11C)

Notes:

- In addition to the course requirements listed above, both the BA and BS degree programs in Physics require the fulfillment of a minimum attendance of Department colloquia. Students should consult with the Department Chair on how to fulfill this requirement.
- For the BS degree PHYS 199 may be substituted for PHYS 175, if approved by the department.
- Students with an interest in theoretical physics are encouraged to consider a minor in Mathematics.
- For students intending to pursue a graduate degree, the study of one foreign language is recommended. Development of computer skills and the acquisition of various machine shop skills are also recommended. Although a minor is not required for the Physics major, a minor in another science or mathematics is recommended.

Requirements • Bachelor of Arts Degree - Physical Science

Units required for Major: 76
Minimum total units required for the BA: 121

Note: Additional units may be required to meet the Sacramento State foreign language requirement.

Courses in parentheses are prerequisites.

The Physical Science major offers a greater diversity than is possible with a major in a single science. Course work is taken in each of the three physical sciences – Physics, Chemistry and the Earth Sciences.

A. Required Lower Division Courses (46 units)

(3)	ASTR 4	Introduction to Astronomy (One year of high school geometry or instructor permission)
(1)	ASTR 6	Astronomical Observation Laboratory (ASTR 4, may be taken concurrently)
(3)	BIO 10	Basic Biological Concepts
(5)	CHEM 1A	General Chemistry I (High school algebra [two years] and high school chemistry; or equivalent)
(5)	CHEM 1B	General Chemistry II (CHEM 1A with a passing grade of "C" or better)
(3)	CHEM 20	Organic Chemistry Lecture – Brief Course (CHEM 1B)
(3)	GEOL 10	Physical Geology
(4)	MATH 30	Calculus I (MATH 29 or four years of high school mathematics which includes two years of algebra, one year of geometry, and one year of mathematical analysis; completion of ELM requirement and Pre-Calculus Diagnostic Test)
(4)	MATH 31	Calculus II (MATH 30 or appropriate high school based AP credit)
(3)	MATH 45	Differential Equations for Science and Engineering (MATH 31)
(4)	PHYS 11A	General Physics: Mechanics (MATH 30, MATH 31; or equivalent certificated high school courses. MATH 31 may be taken concurrently)
(4)	PHYS 11B	General Physics: Heat, Light, Sound (MATH 31, PHYS 11A)
(4)	PHYS 11C	General Physics: Electricity and Magnetism, Modern Physics (MATH 31, PHYS 11A)

B. Required Upper Division Courses (30 units)

(3)	GEOG 111	Elements of Meteorology (GEOG 1 or instructor permission)
(3)	GEOL 121	Geology of California (GEOL 10 or equivalent) **OR**
	GEOL 140	Geology and the Environment
(3)	GEOL 130	Oceanography
(2)	GEOL 184	Geological Field Trip
(3)	PHSC 107	History of the Physical Sciences
(3)	PHYS 106	Introduction to Modern Physics (MATH 31; PHYS 11A, PHYS 11B, PHYS 11C or PHYS 5A, PHYS 5B)
(7)	Select two of the following:	
(4)	PHYS 115	Electronics and Instrumentation (PHYS 11C or PHYS 5B with instructor permission)
(3)	PHYS 130	Acoustics (MATH 45, PHYS 11A, PHYS 11B, PHYS 11C)
(3)	PHYS 145	Optics (MATH 45, PHYS 11A, PHYS 11B, PHYS 11C)
(6)	Select two of the following:	
(3)	CHEM 124	Organic Chemistry Lecture II (CHEM 24, or instructor permission; concurrent enrollment in CHEM 25 recommended.)
(3)	CHEM 125	Advanced Organic Chemistry Laboratory (CHEM 25, CHEM 124, ENGL 20 or an equivalent second semester composition course)
(3)	CHEM 140A	Physical Chemistry Lecture I (CHEM 1B, CHEM 24, CHEM 31, MATH 32; PHYS 5A, PHYS 5B or PHYS 11A, PHYS 11B, PHYS 11C; PHYS 11C may be taken concurrently)
(3)	CHEM 140B	Physical Chemistry Lecture II (CHEM 140A)
(3)	CHEM 161	General Biochemistry (CHEM 20 or CHEM 124)

Requirements • Minor - Physics

Units required for Minor: 21, all of which must be taken in Physics.
A minimum of 9 upper division units is required.
Written approval from a Physics faculty advisor is required.

Courses in parentheses are prerequisites.

A. Required Lower Division Courses (12 units)

(4)	PHYS 11A	General Physics: Mechanics (MATH 30, MATH 31; or equivalent certificated high school courses. MATH 31 may be taken concurrently)
(4)	PHYS 11B	General Physics: Heat, Light, Sound (MATH 31, PHYS 11A)
(4)	PHYS 11C	General Physics: Electricity and Magnetism, Modern Physics (MATH 31, PHYS 11A)

B. Required Upper Division Courses (3 units)

(3) PHYS 106 Introduction to Modern Physics (MATH 31; PHYS 11A, PHYS 11B, PHYS 11C or PHYS 5A, PHYS 5B)

C. Additional Upper Division Requirements (6 units)

Six elective units in Physics selected in consultation with an advisor:

(3) PHYS 105 Mathematical Methods in Physics (MATH 32; PHYS 11A, PHYS 11B, PHYS 11C or PHYS 5A, PHYS 5B)
(3) PHYS 110 Classical Mechanics (MATH 45, PHYS 11C, PHYS 105)
(4) PHYS 115 Electronics and Instrumentation (PHYS 11C or PHYS 5B with instructor permission)
(3) PHYS 124 Thermodynamics and Statistical Mechanics (MATH 45, PHYS 11A, PHYS 11B, PHYS 11C)
(3) PHYS 130 Acoustics (MATH 45, PHYS 11A, PHYS 11B, PHYS 11C)
(3) PHYS 135 Electricity and Magnetism (MATH 45, PHYS 11C, PHYS 105)
(3) PHYS 136 Electrodynamics of Waves, Radiation, and Materials (PHYS 135)
(3) PHYS 142 Applied Solid State Physics (MATH 45, PHYS 106)
(3) PHYS 145 Optics (MATH 45, PHYS 11A, PHYS 11B, PHYS 11C)
(3) PHYS 150 Quantum Mechanics (MATH 45, PHYS 106, PHYS 110)
(3) PHYS 151 Advanced Modern Physics (PHYS 150)
(3) PHYS 162 Computational Physics (two semesters of calculus; PHYS 5A and PHYS 5B or two of the following: PHYS 11A, PHYS 11B or PHYS 11C. Ability to program in a language such as BASIC, PASCAL, FORTRAN or C)
(2) PHYS 175 Advanced Physics Laboratory (12 units of upper division physics including PHYS 106 and either PHYS 115 or PHYS 145 and satisfaction of the Advanced Writing requirement)

Note: PHYS 5A, PHYS 5B may be substituted for PHYS 11A, PHYS 11C, but the 21-unit minimum must be met by additional courses in one of two ways:

PHYS 106 plus three other upper division Physics courses **OR**

PHYS 106 plus PHYS 11B plus two other upper division Physics courses.

Requirements • Minor - Astronomy

Please refer to the Astronomy section within this catalog.

Requirements • Certificate - Scientific Instrument Development

Units required for the Certificate: 11 minimum

A certificate in Scientific Instrument Development is available through the Department of Physics and Astronomy. The Scientific Instrument Development certificate program focuses not only on using scientific instruments, but also will teach the fundamentals of electronics, computer interfacing, and machining. Students that earn this certificate will be prepared to design, prototype, and construct instruments for a wide range of scientific applications. A minimum of 11 units is required.

Specific course requirements are:

(2) PHSC 75 Introduction to Machine Shop Practices
(4) PHYS 115 Electronics and Instrumentation (PHYS 11C or PHYS 5B, instructor permission)
(3) PHYS 116 Advanced Electronics and Instrumentation (PHYS 115)
(2-4) Select one of the following:
(4) CHEM 133 Chemical Instrumentation (CHEM 31, CHEM 140B, or CHEM 142, instructor permission, ENGL 20 or an equivalent second semester composition course)
(3) CHEM 141 Physical Chemistry Laboratory (ENGL 20 or an equivalent second semester composition course, CHEM 140A, CHEM 140B or CHEM 142, instructor permission, CHEM 140B may be taken concurrently)
(2-3) GEOL 197 Advanced Laboratory Techniques in Geology (appropriate upper division courses and instructor permission)
(2) PHYS 175 Advanced Physics Laboratory (12 units of upper division physics including PHYS 106 and either PHYS 115 or PHYS 145 and a satisfaction of the Advanced Writing requirement)

To receive the certificate in Scientific Instrument Development, students must

- achieve a 2.5 GPA in the certificate program courses;
- must be working towards a degree at Sacramento State or have special approval from the Chair of the Department of Physics and Astronomy.

Requirements • Subject Matter Program (Pre-Credential Preparation)

Physics majors who intend to pursue a single subject teaching credential must complete a BA in Physics including courses in the Science Subject Matter Program which is described in more detail under the heading "Science Subject Matter Program" in this catalog. Upon successful completion, this program fulfills the subject matter competence requirement and qualifies students to enter the Teaching Credential Program in the School of Education. The science teaching credential with a concentration in Physics allows candidates to teach all four of the natural sciences (Biology, Chemistry, Geoscience, and Physics) at the general science level and Physics at an advanced level in high school.

Currently there is a serious need in public school education for well-educated science teachers. Physics majors who have an interest in teaching should see the credential advisor in the Department (Dr. Gary Shoemaker, *shoemaker@csus.edu*) to plan an academic program and to explore ways to get involved in teaching-related activities such as tutoring, grading, and working in the schools.

Note: Due to policy changes from the California Commission on Teacher Credentialing and the federal No Child Left Behind mandate, the Subject Matter program was under review at the time of this catalog printing and is subject to revision. As a result it is important to consult a credential advisor for current details.

Lower Division Courses

Physical Science

PHSC 75. Introduction to Machine Shop Practices. Safe machine operation techniques on common fabrication equipment. Study of materials and methods used to build testing and measuring equipment. Reading and calibrating measuring devices, gauging and optical gauging. Study of measuring conventions and understanding of precision. Interpretation of drawings, tolerances and tactics for maintaining tolerances. Jigs and mounts for dynamic data collection equipment. Prototype manufacturing. Students completing this course qualify to perform work in the shop with minimum supervision. Lecture one hour; Laboratory three hours. **Units:** 2.0.

Physics

PHYS 1. Physical Reasoning and Calculation. Introduction to the analytical skills needed for the study of Physics. The focus is to prepare students to take PHYS 11A, however, PHYS 1 is also suitable as preparation for PHYS 5A. Emphasis is on reasoning and problem-solving, including conceptualization, visualization, and interpretation of written descriptions of physical situations, and on the connection of physical laws to the mathematical techniques used in their solution. **Units:** 2.0.

PHYS 2. Topics in Elementary Physics. One semester introductory physics course including a laboratory. Covers the fundamental concepts of physics with an emphasis on everyday life situations and applications. The range of material includes mechanics, waves, electricity and optics. One hour lecture, two hour discussion, and a three hour laboratory session. **Prerequisite:** A recent one year course in high school algebra and one year of plane geometry or a college course in algebra (MATH 9). **Units:** 4.0.

PHYS 5A. General Physics: Mechanics, Heat, Sound. Physics 5A-B sequence is a two-semester course in introductory physics in which fundamental concepts are emphasized including some physiological applications. These courses satisfy the requirement for pre-medical and pre-dental students and biology majors. Lecture one hour; quiz two hours; laboratory three hours. **Prerequisite:** Recently completed three years of high school algebra and geometry; and a college course in algebra and trigonometry (MATH 9 recommended) for those having an inadequate mathematics background. **Units:** 4.0.

PHYS 5B. General Physics: Light, Electricity and Magnetism, Modern Physics. Lecture one hour; quiz two hours; laboratory three hours. **Prerequisite:** PHYS 5A or instructor permission. **Units:** 4.0.

PHYS 10. Physics in Our World. Introductory course designed for non-science students completing general education requirements. Students will be introduced to basic concepts in Physics through the study of astronomy, atomic nature of matter, electromagnetic waves, energy, sound and earthquake waves, current electricity, magnetism, and nuclear processes. Development of reasoning and quantitative skills and applying them to scientific and technological topics of current importance will be emphasized. **Units:** 3.0.

PHYS 10L. Physics in Our World Laboratory. Laboratory course complements PHYS 10 and satisfies the general education science lab requirement. Emphasis is placed on the nature of scientific observation and measurement and their relationship to general physical concepts. Students will be given a concrete, hands-on sense of observing and interpreting data from a variety of experimental environments. **Prerequisite:** PHYS 10; may be taken concurrently. **Units:** 1.0.

PHYS 11A. General Physics: Mechanics. PHYS 11A, 11B, 11C sequence is a three semester course in introductory physics requiring elementary calculus. This sequence satisfies the lower division physics requirement for a major in physics, physical science, chemistry, geology, or engineering. Lecture two hours; quiz two hours; laboratory three hours. **Prerequisite:** MATH 30, MATH 31; or equivalent certificated high school courses. MATH 31 may be taken concurrently. **Units:** 4.0.

PHYS 11B. General Physics: Heat, Light, Sound. Lecture one hour; quiz two hours; laboratory three hours. **Prerequisite:** MATH 31, PHYS 11A. **Units:** 4.0.

PHYS 11C. General Physics: Electricity and Magnetism, Modern Physics. Lecture one hour; quiz two hours; laboratory three hours. **Prerequisite:** MATH 31, PHYS 11A. **Units:** 4.0.

PHYS 30. Science and Pseudoscience. Examination of the methodology of science. Comparison of legitimate investigations with others that do not meet high scientific standards, including both science poorly done and nonsense posing as science. Examples will be drawn primarily from the physical sciences. Analyzes will require study of basic skills of reasoning, types of logical argument, structure and validity of arguments, common reasoning fallacies, critical evaluation of evidence, and understanding of the scientific thinking process. **Units:** 3.0.

PHYS 99. Special Problems. Individual projects or directed reading. **Note:** Open only to students who appear competent to assume individual work on the approval of the instructor. For students with lower division status. Up to 4 units may be taken for grade. **Graded:** Graded (CR/NC Available). **Units:** 1.0-3.0.

Upper Division Courses

Physical Science

PHSC 107. History of the Physical Sciences. Study of the development of the major physical laws presently used in describing our physical world. Some considerations of the influences of these developments on other areas of knowledge and on society in general. **Cross-listed:** HIST 107; only one may be counted for credit. **Units:** 3.0.

PHSC 196. Experimental Offerings in Physical Science. When a sufficient number of qualified students apply, one of the staff will conduct a seminar in some topic in one of the physical sciences. **Units:** 1.0-3.0.

PHSC 199. Special Problems. Individual projects or directed reading. **Note:** Open only to students who appear competent to assume individual work on the approval of the instructor. Up to 4 units may be taken for grade. **Graded:** Graded (CR/NC Available). **Units:** 1.0-3.0.

Physics

PHYS 105. Mathematical Methods in Physics. Linear algebra and linear vector spaces, linear transformations and eigenvectors, differential and integral vector calculus, with applications to physical problems. **Prerequisite:** MATH 32; PHYS 11A, PHYS 11B, PHYS 11C or PHYS 5A, PHYS 5B. **Units:** 3.0.

PHYS 106. Introduction to Modern Physics. Basic concepts of special relativity and quantum theory of matter. Phenomenological study of atomic and molecular energy states and spectra. Elements of solid-state and nuclear physics. **Prerequisite:** MATH 31; PHYS 11A, PHYS 11B, PHYS 11C or PHYS 5A, PHYS 5B. **Units:** 3.0.

PHYS 107. Conceptual Physics and Scientific Inquiry. Concepts include matter, waves and energy, force and motion, electricity and magnetism, and scientific inquiry. Emphasizes hands on cooperative learning engaging students in scientific inquiry by posing testable scie ntific questions, conducting experiments, and analyzing and presenting findings to their peers. Appropriate for Liberal Studies and Blended Multiple Subject Credential students. Two activity sessions per week. **Prerequisite:** BIO 7, CHEM 106, GEOL 8, MATH 17. **Units:** 4.0.

PHYS 110. Classical Mechanics. Fundamental principles of statics and dynamics, including Newton's equations and conservation laws, damped and forced oscillations, central force motion, accelerated coordinate systems, coupled oscillations, normal modes, Lagrangian and Hamiltonian methods, introduction to nonlinear systems and chaos theory. **Prerequisite:** MATH 45, PHYS 11C, PHYS 105. **Units:** 3.0.

PHYS 115. Electronics and Instrumentation. Linear and nonlinear circuits, operational amplifiers, transducers, basics of digital circuitry, and an introduction to computerized data acquisition. Lecture two hours; laboratory six hours. **Prerequisite:** PHYS 11C or PHYS 5B with instructor permission. **Units:** 4.0.

PHYS 116. Advanced Electronics and Instrumentation. Noise reduction techniques, signal recovery, frequency analysis, computerized instrument control, and instrument development. Lecture one hour; laboratory six hours. **Prerequisite:** PHYS 115. **Units:** 3.0.

PHYS 124. Thermodynamics and Statistical Mechanics. Basic concepts and laws of thermodynamics and thermal properties of matter; kinetic theory of gases; use of distribution functions and ensembles in statistical mechanics; connection of probability and entropy; quantum statistics; applications to various systems. **Prerequisite:** MATH 45, PHYS 11A, PHYS 11B, PHYS 11C. **Units:** 3.0.

PHYS 130. Acoustics. Theoretical and experimental study of sound sources, sound waves and sound measurement. Basic properties of waves in continuous media; spectral analysis of vibrations; use of acoustic impedance and circuit analogies; applications to environmental noise analysis, room acoustics, and loudspeaker and microphone design and use; experience with acoustic instrumentation. Lecture two hours; laboratory three hours. **Prerequisite:** MATH 45, PHYS 11A, PHYS 11B, PHYS 11C. **Units:** 3.0.

PHYS 135. Electricity and Magnetism. Development of electromagnetic theory from basic experimental laws; electrostatics, electric currents, magnetostatics, electric and magnetic properties of matter, induction, Maxwell's equations, conservation laws, introduction to electromagnetic waves. **Prerequisite:** MATH 45, PHYS 11C, PHYS 105. **Units:** 3.0.

PHYS 136. Electrodynamics of Waves, Radiation, and Materials. Electromagnetic waves, wave propagation in material media, reflection and refraction, polarization, cavities and waveguides, optical fibers, simple radiating systems, radiation from an accelerated charge and special relativity. Introduction to plasma physics and electromagnetic properties of superconductors. **Prerequisite:** PHYS 135. **Units:** 3.0.

PHYS 142. Applied Solid State Physics. Elementary treatment of crystal structure and lattice and electron dynamics. Physics of semiconductor junctions, diodes, transistors and MOSFETS, solar cells, lasers, electro-optic and acousto-optic devices. Introduction to basic physical properties such as electrical conduction of selected amorphous solids and their applications. Laboratory experience. **Prerequisite:** MATH 45, PHYS 106. **Units:** 3.0.

PHYS 145. Optics. Theoretical and experimental treatment of wave optics; interference, diffraction, absorption, scattering, dispersion, polarization. Selected topics from contemporary optics: Fourier optics, coherence theory, lasers, holography. Lecture two hours; laboratory three hours. **Prerequisite:** MATH 45, PHYS 11A, PHYS 11B, PHYS 11C. **Units:** 3.0.

PHYS 150. Quantum Mechanics. Foundations of wave mechanics, including wave packets, superposition, and the uncertainty principle. The Schroedinger equation and its relation to operators and eigenstates. Symmetric systems and conserved quantities. Introduction to matrix mechanics, spin, scattering, and perturbation theory. **Prerequisite:** MATH 45, PHYS 106, PHYS 110. **Units:** 3.0.

PHYS 151. Advanced Modern Physics. Structure of matter including basic elements of atomics, molecular, solid state, nuclear and particle physics. Topics will also include photon and electron gases, lasers, superconductivity, Bose-Einstein condensation and superfluidity. **Prerequisite:** PHYS 150. **Units:** 3.0.

PHYS 156. Classical and Statistical Mechanics. Review of classical mechanics, Lagrangian and Hamiltonian formulations, rigid body motion, small vibrations and normal modes, nonlinear dynamics and chaos. Review of the laws of thermodynamics, principles of classical statistical mechanics, ensemble formulations and applications, principles of quantum statistical mechanics, ideal quantum gases, applications to Fermi-Dirac and Bose-Einstein systems. **Prerequisite:** PHYS 110, PHYS 124. **Units:** 3.0.

PHYS 162. Computational Physics. Study of methods and development of skills for application of computers in solution of physical problems. Calculation techniques, modeling and simulation, data acquisition and manipulation, and use of programming resources. Practical experience in methods. **Prerequisite:** Two semesters of calculus; PHYS 5A and PHYS 5B or two of the following: PHYS 11A, PHYS 11B, or PHYS 11C. Ability to program in a language such as BASIC, PASCAL, FORTRAN or C. **Units:** 3.0.

PHYS 175. Advanced Physics Laboratory. Advanced experiments chosen from several of the major areas of physics, performed usually on an individual basis. Laboratory six hours. **Prerequisite:** 12 units of upper division physics, including PHYS 106 and either PHYS 115 or PHYS 145 and satisfaction of the Advanced Writing requirement. **Units:** 2.0.

PHYS 186. Musical Acoustics: Science and Sound. Physical principles of vibration and wave motion, with illustrations involving musical instruments and concert hall acoustics; principles of electronic synthesis, recording, and reproduction of sound; operation of the human ear and brain in receiving and analyzing sound; relation of the harmonic series to sound quality, harmony and scales; proper roles for science in explaining music as an artistic activity. **Note:** No technical background required; course cannot be used to meet Physics BS program requirements. **Cross-listed:** MUSC 186; only one may be counted for credit. **Units:** 3.0.

PHYS 190. Physics Seminar. Special lecture series on announced topics by local and visiting speakers, emphasizing current research developments, with related reading assignments. May be taken twice for credit. **Units:** 1.0-2.0.

PHYS 191. Senior Project. Research Project under faculty supervision. Project may consist of laboratory or theoretical research project, instrumentation/demonstration development, or literature research project. Projects require written and oral reports. **Note:** May be taken twice for credit in sequential semesters for a maximum of two units total. Grade assigned upon completion of the project. **Prerequisite:** Department chair permission. **Units:** 1.0-2.0.

PHYS 194. Physics Related Work Experience. Supervised employment in a physics or astronomy related company or agency. Placement is arranged through the department and the Cooperative Education Program office. Requires completion of a three-to-six month work assignment and a written report. **Note:** PHYS 194 may not be used to meet major requirements in Physics. **Prerequisite:** Upper-division status and Department Chair permission. **Graded:** Credit / No Credit. **Units:** 6.0-12.0.

PHYS 196. Experimental Offerings in Physics. To be offered in the various fields of physics in response to student demand. **Prerequisite:** Appropriate upper division course work and instructor permission. **Units:** 1.0-3.0.

PHYS 198. Co-Curricular Activities. Students may provide special tutoring to students taking physics courses, participate in community oriented projects, assist in activity sessions for teacher training courses, or engage in activities related to the subject matter and concerns of the Physics and Astronomy Department. Up to 4 units may be taken. **Graded:** Credit / No Credit. **Units:** 1.0-3.0.

PHYS 199. Special Problems. Individual projects or directed reading. Open only to students who appear competent to assume individual work on the approval of the instructor. Up to 4 units may be taken for grade. **Graded:** Graded (CR/NC Available). **Units:** 1.0-3.0.