PHYSICS

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Courses in Physics have the subject code PHYSICS. For a complete list of subject codes, see Appendix B.

The Russell H. Varian Laboratory of Physics, the nearby W. W. Hansen Experimental Physics Laboratory (HEPL), the E. L. Ginzton Laboratory, and the Geballe Laboratory for Advanced Materials (GLAM) together house a range of physics activities from general courses through advanced research. At the Stanford Free Electron Laser Center, located in HEPL, tunable picosecond optical beams are available for materials and biomedical research at wavelengths that extend from the visible to the far infrared. Ginzton Lab houses research on optical systems, including quantum electronics, metrology, optical communication and development of advanced lasers. GLAM houses research on novel and nanopatterned materials, from high-temperature superconductors and magnets to organic semiconductors, subwavelength photon waveguides, and quantum dots. GLAM also supports the broader materials community on campus with a broad range of characterization tools, and will be the site for Stanford's new Nanocharacterization Lab.

The Stanford Linear Accelerator Center (SLAC) is just a few miles from the Varian Laboratory. SLAC is a high-energy physics lab with a two-mile-long linear accelerator that can accelerate electrons and positrons up to 50 GeV, and produce highly polarized electron beams. The PEP-II asymmetric-energy electron-positron storage ring is used to study CP violation in the B meson system. The Stanford Synchrotron Radiation Laboratory (SSRL) uses intense x-ray beams produced with another smaller storage ring on the SLAC site.

The Ginzton Laboratory, HEPL, GLAM, SLAC, and SSRL are listed in the "Academic Programs and Centers, Independent Research Laboratories, Centers, and Institutes" section of this bulletin. Students may also be interested in research and facilities at two other independent labs: the Center for Integrated Systems, focused on electronics and nanofabrication; and the Clark Center, a new interdisciplinary biological sciences laboratory, due to open in August 2003.

The Physics Department and SLAC have together launched the Kavli Institute for Particle Astrophysics and Cosmology, a new institute serving as a focus of Stanford research in this interdisciplinary area. Substantial increase in the associated faculty, and in student opportunities for research in astrophysics and cosmology, is under way. Stanford is a member of the Hobby-Eberly Telescope Consortium, operating an innovative 10.4 meter telescope at McDonald Observatory in Texas. Students may also participate in research using this instrument. A particle astrophysics program of searches for dark matter, the CDMS (cryogenic dark matter search) experiment, is operated in an underground laboratory on the Stanford campus and in the Soudan mine in Minnesota.

The Stanford Institute for Theoretical Physics is devoted to the investigation of basic structure of matter (string theory, M-theory, quantum cosmology, condensed matter physics).

The Physics Library, a center for the reading and study of physics and astronomy at all levels, includes print and electronic access to current subscriptions and back sets of important journals together with textbooks, dissertations, scholarly monographs, and the collected works of the most eminent physicists.

Course work is designed to provide students with a sound foundation in both classical and modern physics. Students who wish to specialize in astronomy, astrophysics, or space science should consult the "Astronomy Course Program" section of this bulletin.

Three introductory series of courses include labs in which undergraduates carry out individual experiments. The Intermediate and Advanced Physics Laboratories offer facilities for increasingly complex individual work. Laboratories provide students with a sound basis for more advanced laboratory work, including the conception, design, and fabrication of laboratory equipment. Undergraduates are also encouraged to participate in research; most can do this through the honors program and/or the summer research program.

Graduate students find opportunities for research in the fields of astrophysics, atomic physics/laser science, biophysics, coherent optical radiation, condensed matter physics, high energy physics, particle astrophysics, intermediate energy physics, low temperature physics, materials research, novel imaging technologies, quantum electronics and theoretical physics. Faculty advisers are drawn from multiple departments, including Physics, Applied Physics, Materials Science and Engineering, Electrical Engineering, and Biological Sciences. Opportunities for research are also available with the faculty at SLAC in the areas of theoretical and experimental particle physics and accelerator design.

The number of graduate students admitted to the Department of Physics is strictly limited. Students should submit applications by January 1 for the following Autumn Quarter. Graduate students may normally enter the department only at the beginning of Autumn Quarter.

UNDERGRADUATE PROGRAMS

The study of physics is undertaken by three principal classes of undergraduates: those including physics as part of a general education; those preparing for careers in professional fields that require a knowledge of physics, such as medicine or engineering; and those preparing for teaching or research careers in physics or related fields. Physics courses numbered below 200 are intended to serve all three of these groups. The courses numbered above 200 meet the needs mainly of the third group, but also of some students majoring in other branches of science and in engineering.

ENTRY-LEVEL SEQUENCES

The Department of Physics (PHYSICS) offers three year-long entry level physics sequences, the PHYSICS 20, 50 (formerly 40), and 60 series. The first of these is non-calculus-based, and is intended primarily for those who are majoring in the biological sciences. Such students with AP credit, particularly those who are considering research careers, may wish to consider taking the physics series, however, as it provides adequate depth and emphasis on problem solving to be of significantly more value in biological research which today involves considerable physics based technology.

For those intending to major in engineering or the physical sciences, or simply wishing a stronger background in physics, the department offers the PHYSICS 50 and 60 series. Either of these will satisfy the entry level physics requirements of any Stanford major. Both cover the same topics in three terms, but the 60 series is intended for those who have already taken a Physics course at the level of the 50 series, or at least have a strong background in mechanics as well as a strong background in calculus. The 50 series begins with the topics of light and heat in PHYSICS 51 and proceeds to mechanics in 53 and electricity and magnetism in 55. It is recommended that most students begin this sequence in the Winter Quarter with mechanics in PHYSICS 53. Only those who have had strong physics preparation in high school (e.g., a score of at least 4 on the Physics Advanced Placement B or C exam) are recommended to start with PHYSICS 51 in Autumn Quarter.

BACHELOR OF SCIENCE

A calculus-based entry level series is required, either PHYSICS 61, 63, 64, 65, and 67 or 51, 52, 53, 55, and 56 (or preferably 67 rather than 56). In addition, the following more advanced courses are required: 70, 105, 107 (WIM), 108, 110, 120, 121, 130, 131, 170, and 171; MATH 51, 52, 53, 131; one additional Mathematics course numbered 100 or higher, or PHYSICS 112. MATH 51H, 52H, and 53H may substitute for MATH 51, 52, and 53. It is strongly recommended that students intending to complete a Ph.D. in Physics also take PHYSICS 113, 134 and one or more of the following, depending upon their interests: 160, 161, 172, 181, 204 and/or 262. PHYSICS 113 is designed to be taken in parallel with 110. The department advises the study of some computer science, for example, CS 106. Mathematics and Physics courses taken to satisfy the department's major requirements cannot be taken on a credit/no credit basis. Prospective Physics majors are also recommended to take PHYSICS 59, Current Research Topics.

To decide which introductory sequence is appropriate, students contemplating majoring in Physics are urged to consult with the instructor of PHYSICS 61 or 51, or the Undergraduate Program Coordinator, at the earliest possible date to see which sequence is the most suitable. Students who begin taking an entry level Physics course after their freshman year and wish to major in Physics are generally advised to take the PHYSICS 61, 63, 65 sequence, provided they have previously taken MATH 41.

Undergraduates are offered help with physics problems in the department tutoring center, the Reference Frame, which is staffed Monday through Thursday.

REQUIRED COURSES FOR MAJORS

INTRODUCTORY SEQUENCE

Course No. and Subject	*Qtr. and*	*Units*
PHYSICS 51. Light and Heat	A	4
PHYSICS 52. Light and Heat Lab	A	1
PHYSICS 53. Mechanics	W	4
PHYSICS 55. Electricity and Magnetism	S	4
PHYSICS 56. Electricity and Magnetism Lab	S	1
(PHYSICS 67 is recommended for prospective majors)	S	2
or		
PHYSICS 61. Mechanics	A	4
PHYSICS 63. Electromagnetism	W	4
PHYSICS 64. Electromagnetism Lab	W	1
PHYSICS 65. Thermodynamics and Optics	S	4
PHYSICS 67. Introduction to Laboratory Physics	S	2
and		
MATH 51, 52, 53. Multivariable Math (or H series)	A,W,S	15
PHYSICS 59. Current Research Topics (recommended)*	A	1

INTERMEDIATE SEQUENCE

PHYSICS 70. Modern Physics	A	4
PHYSICS 105. Physics Laboratory I: Analog Electronics	A	3
PHYSICS 107. Physics Laboratory II: Analysis (WIM)	W	4
PHYSICS 108. Physics Laboratory III: Project	S	3
PHYSICS 110. Intermediate Mechanics	S	4
PHYSICS 112. Math Methods of Physics (recommended)**	W	4
PHYSICS 113. Computational Physics (recommended)*	S	4
PHYSICS 120,121. Intermediate Electricity and Magnetism	W,S	8
and MATH 131. Partial Differential Equations	A,W,S	3

ADVANCED SEQUENCE

PHYSICS 130,131. Quantum Mechanics	A,W	8
PHYSICS 134. Advanced Topics in Quantum Mechanics*	S	4
PHYSICS 170,171. Statistical Mechanics	A,W	8
PHYSICS 290. Research Activities at Stanford*	A	1-3
and one advanced Mathematics elective (100 level or higher)		
or PHYSICS 112		

* These courses are not required, but 113, 134, and 290 are recommended for students who intend to complete a Ph.D. in Physics.

** Those wishing to do physics theory in graduate school may wish to take a collection of math courses in the Department of Mathematics rather than PHYSICS 112.

CONCENTRATION IN PHYSICS

The primary purpose of concentrations in the Physics major is to provide consistent and more formal advising to students who want to concentrate in a particular area of physics during their undergraduate education, or prepare for future studies (e.g., graduate studies) in a particular area of physics. Physics majors are not required to choose a concentration and a concentration does not add any formal requirements to the Physics major. Upon graduation, students will receive a certificate of completion of a concentration.

Students seeking further advice on a given concentration should contact the professor whose name appears next to the respective title of each section below.

A. THEORETICAL PHYSICS (Andrei Linde)

At least four, one quarter courses selected from the following courses, or three courses plus an honors thesis:

Course No. and Subject
PHYSICS 204. Advanced Seminar in Theoretical Physics
PHYSICS 212. Statistical Mechanics
PHYSICS 230, 231, 232. Quantum Mechanics
PHYSICS 252. Introduction to High Energy Physics
PHYSICS 260. Introduction to Astrophysics and Cosmology
PHYSICS 262. Introduction to Gravitation
PHYSICS 330, 331, 332. Quantum Field Theory
PHYSICS 351, 352. Elementary Particle Physics
PHYSICS 362. Advanced Extragalactic Astrophysics and Cosmology
PHYSICS 364. Advanced Gravitation

Notes to students taking this concentration:

1. No more than one of the courses should be taken for CR/NC.
2. Students should take either the undergraduate Quantum Mechanics series (PHYSICS 130-132) or the graduate series (PHYSICS 230-232), but not both for credit.
3. Students should discuss the choice of courses with members of the Institute for Theoretical Physics and/or their major adviser.

B. APPLIED PHYSICS (Hari Manoharan)

At least four, one quarter courses selected from the following courses, or three courses plus an honors thesis:

Solid State:

APPPHYS 172. Physics of Solids I
APPPHYS 196. Scattering Physics
APPPHYS 270. Magnetism and Long Range Order in Solids
MATSCI 195. Waves and Diffraction in Solids

Biophysics:

APPPHYS 192. Introductory Biophysics

Accelerator Physics:

APPPHYS 198. Introduction to Synchrotron Radiation

Lasers:

PHYSICS 181. Introduction to Modern Optics
APPPHYS 231A. Introduction to Lasers

Lab Methods:

APPPHYS 207, 208. Laboratory Electronics, Analog and Digital
APPPHYS 304. Lasers Laboratory

C. BIOPHYSICS (David Goldhaber-Gordon)

We recommend that Physics majors interested in pursuing a career in biophysics consider a minor in Biological Sciences.

D. ASTROPHYSICS (Roger Romani, Sarah Church)

Requirements:

PHYSICS 100. Introduction to Observational and Laboratory Astronomy
PHYSICS 160. Introduction to Stellar and Galactic Astrophysics
PHYSICS 161. Introduction to Extragalactic Astrophysics and Cosmology

Plus one elective from below or an honors thesis:

PHYSICS 211. Continuum Mechanics
PHYSICS 260. Introduction to Astrophysics and Cosmology
PHYSICS 262. Introduction to Gravitation
PHYSICS 312. Basic Plasma Physics
(prerequisites are PHYSICS 210 and PHYSICS 220)

E. GEOPHYSICS (Rosemary Knight, Geophysics)

At least four, one quarter courses selected from the following courses, or three courses plus an honors thesis:

GEOPHYS 102. Geosphere
GEOPHYS 112. Exploring Geosciences with MATLAB
GEOPHYS 140. The Earth from Space: Introduction to Remote Sensing
GEOPHYS 150. General Geophysics and Physics of the Earth
GEOPHYS 180. Geophysical Inverse Problems
GEOPHYS 182. Reflection Seismology
GEOPHYS 190. Environmental and Applied Geophysics
GEOPHYS 262. Rock Physics
GEOPHYS 288. Crustal Deformation

MINORS

Students who take the 20 or 50 series at Stanford in support of their major may count those units towards the minor. Those who have fulfilled Physics requirements at the 20 or 50 series level by enrollment at another accredited university, or through advanced placement credits, may count credits towards 21 and 23, or 53 and 55, respectively. 25/26, or 51/52 for a technical minor, should be taken at Stanford even if similar material has been covered elsewhere. With the 21/23 or 53/55 exception noted above, all courses for the minor must be taken at Stanford University for a letter grade, and a grade of 'C' or better must be received for all units applied toward the minor. The minor declaration deadline is three quarters before graduation, i.e., beginning of Autumn Quarter if the student is graduating at the end of Spring Quarter.

MINOR IN PHYSICS

An undergraduate minor in Physics requires the following course work:

Non-Technical—For students whose majors do not require the PHYSICS 50 or 60 series:

Course No.	*Units*
PHYSICS 21, 22, 23, 24, 25, and 26	12
Any combination of Physics courses totaling 15 units or greater	15
Total	27

Technical—For students whose majors require the PHYSICS 50 or 60 series:

Course No.	
PHYSICS 70	4
Any three courses above PHYSICS 100	9-12
Total	13-16

MINOR IN ASTRONOMY

Students wishing to pursue advanced work in astrophysical sciences should major in physics and concentrate in astrophysics. However, students outside of physics with a general interest in astronomy may organize their studies by completing one of the following minor programs.

An undergraduate minor in astronomy requires the following course work:

Non-Technical—For students whose majors do not require the PHYSICS 50 series:

Course No.	*Units*
PHYSICS 21, 23, 25/26	10
PHYSICS 50 or 100 (Observatory Lab)	3-4
Choose two courses from the following:	
PHYSICS 15, 16, 17, 18	6
Total	19-20 (9-10 in addition to the 20 series)

Technical—For students whose majors require the PHYSICS 50 series:

Course No.	*Units*
PHYSICS 51/52, 53, 55	13
PHYSICS 70	4
PHYSICS 100 (Observatory Lab)	4
Choose two courses from the following:	
PHYSICS 160,* 161,* 164*	6
Total	27 (14 in addition to the 50 series)

* With approval of the minor adviser and the chair of the Astronomy Course Program, 3 units of PHYSICS 169, Independent Study in Astrophysics, may be substituted for one course of astronomy (e.g., 160, 161, 164). This independent study can either be constituted as a directed reading program or participation in a research project. Students are also strongly encouraged to take the electricity and magnetism/optics lab of the appropriate Physics series (24, 56) for 1 additional unit.

To be accepted to the minor program, the student must obtain an adviser from the faculty in the Astronomy Course Program.

HONORS PROGRAM

The department offers a program leading to the degree of Bachelor of Science in Physics with Honors as follows:

1. Students must submit an Honors Program Proposal to the Undergraduate Program Coordinator once they find a physics project, either theoretical or experimental, in consultation with individual faculty members. Proposal forms are available from the Physics Undergraduate Center and must be submitted by November 1 of the year in which the students' degree will be conferred.
2. Credit for the project is assigned by the adviser within the framework of PHYSICS 205 or ASTRNMY 169. The work done in the honors program may not be used as a substitute for regularly required courses.
3. Both a written report and a presentation of the work at its completion is required for honors. By mid-May, each honors candidate is required to present his or her project at the department's Honors Presentations. (This event is publicized and is open to the general public. The expectation is that the student's adviser and second reader, along with all other honors candidates, will attend.)
4. The decision as to whether a given independent study project does or does not merit award of honors is made jointly by the student's honors adviser and the second reader for the written thesis. This decision is based on the quality of both the honors work and the other work in physics.

GRADUATE PROGRAMS

MASTER OF SCIENCE

The department does not offer a coterminal degree program, or a separate program for the M.S. degree, but this degree may be awarded for a portion of the Ph.D. degree work.

University requirements for the master's degree, discussed in the "Graduate Degrees" section of this bulletin, include registration for at least three quarters at full tuition as a graduate student and completion of 36 units of course work after the bachelor's degree. Among the department requirements are a grade point average (GPA) of at least 3.0 (B) in courses 210, 211, 212, 220, 221, 230, 231, 232, or their equivalents. Up to 6 of these required units may be waived on petition if a thesis is submitted.

DOCTOR OF PHILOSOPHY

The University's basic requirements for the Ph.D. are discussed in the "Graduate Degrees" section of this bulletin. The minimum department requirements for the Ph.D. degree in Physics consist of completing all courses listed below, and at least one quarter from each of two subject areas (among condensed matter, quantum optics and atomic physics, astrophysics and gravitation, and nuclear and particle physics) chosen from courses with numbers above 232, except 290 and 294. The requirements in the following list may be fulfilled by passing the course at Stanford or passing an equivalent course elsewhere: 210, 211, 212, 220, 221, 230, 231, 232, 290, 294. A grade point average (GPA) of at least 3.0 (B) is required in all the courses taken toward the degree.

All Ph.D. candidates must have math proficiency equivalent to the following Stanford math courses: 106, 113, 114, 130, 131.

Prior to making an application for candidacy, each student is required to pass a comprehensive qualifying examination on undergraduate physics. This closed book exam is given in the month of January immediately following the student's arrival at Stanford. This is a written examination held over two days, covering particle mechanics, electricity and magnetism, quantum mechanics, statistical mechanics, thermodynamics, special relativity, and general physics. A thesis proposal must be submitted during the third year. In order to assess the direction and progress toward a thesis, an oral report and evaluation is required during the fourth year. After completion of the dissertation, each student must take the University oral examination (defense of dissertation).

Three quarters of teaching (including a demonstrated ability to teach) are a requirement for obtaining the Ph.D. in Physics.

Students interested in applied physics and biophysics research should also take note of the Ph.D. granted independently by the Department of Applied Physics and by the Biophysics Program. Students interested in astronomy, astrophysics, or space science should also consult the "Astronomy Course Program" section of this bulletin.

Ph.D. MINOR

Minors in Physics must take at least six courses numbered 210 to 232 among the 20 required units. All prospective minors must obtain approval of their Physics course program from the Physics Graduate Study Committee at least one year before award of the Ph.D.

FELLOWSHIPS AND ASSISTANTSHIPS

The Department of Physics makes an effort to support all its graduate students through fellowships, teaching assistantships, research assistantships, or a combination of sources. Information on application procedures is mailed with the admission information.

TEACHING CREDENTIALS

For information on teaching credentials, consult the "School of Education" section of this bulletin or address an inquiry to the Credential Administrator, School of Education.

COURSES

There are four series of beginning courses. One course from the teen series (11, 15, 16, 17, 19) is recommended for the humanities or social science student who wishes to become familiar with the methodology and content of modern physics. The 20 series (21, 22, 23, 24, 25, 26) is recommended for general students and for students preparing for medicine or biology. The 50 series (51, 52, 53, 55, 56) is for students of engineering, chemistry, geology, mathematics, or physics. The advanced freshman series (61, 63, 64, 65, 67) is for the well-prepared student and is the preferred introductory series for those Physics majors who have the appropriate background.

Both the 20 and 50 series consist of demonstration lectures on the fundamental principles of physics, problem work on application of these principles to actual cases, and lab experiments correlated to the lectures. Their objectives are not only to give information on particular subjects, but also to provide training in the use of the scientific method. The primary difference between the two series of courses is that topics are discussed more thoroughly and treated with greater mathematical rigor in the Fifty Series.

Courses beyond 99 are numbered in accordance with a three-digit code. The first digit indicates the approximate level of the course:

100	undergraduate courses
200	first-year graduate courses
300	more advanced courses
400	research, special, or current topics

The second digit indicates the general subject matter:

00	laboratory
10,20,30	general courses
40	nuclear physics
50	elementary particle physics
60	astrophysics, cosmology, gravitation
70	condensed matter physics
80	optics and atomic physics
90	miscellaneous courses

UNDERGRADUATE

(WIM) indicates that the course satisfies the Writing in the Major requirements.

ASTRONOMY

For further information on astronomy and astrophysics courses, consult the Astronomy Course Program.

PHYSICS 15,16,17. Topics in Modern Astronomy—Designed for, but not restricted to, undergraduates not majoring in the physical sciences. Emphasis is on aspects of modern astronomy, astrophysics, and cosmology. No mathematics beyond algebra used. Courses may be taken individually or in sequence.

PHYSICS 15. The Nature of the Universe—Introduction to the structure, origin, and evolution of the major components of the Universe: planets, stars, and galaxies. Emphasis is on the formation of the Sun and planets, the evolution of stars, and the structure and content of our galaxy. Topics: cosmic enigmas (dark matter, black holes, pulsars, x-ray sources), star birth and death, and the origins of and search for life in our solar system and beyond. GER:2a

3 units, Aut (Romani)

PHYSICS 16. Cosmic Horizons—Introduction to the origin and evolution of our universe and its contents: stars, galaxies, quasars. The overall structure of the cosmos and the physical laws that govern matter, space, and time. Topics include the evolution of the cosmos from its primeval fireball, the origin of the elements and the formation of stars and galaxies, exotic astronomical objects (black holes, quasars, supernovae, and gamma ray bursts), dark matter, and the fate of the cosmos. GER:2a

3 units, Win (Cabrera)

PHYSICS 17. Black Holes—Newton's and Einstein's theories of gravitation and their relationship to the predicted properties of black holes. Their formation and detection, and their role in galaxies and high-energy jets. Hawking radiation and aspects of quantum gravity. GER:2a

3 units, Spr (Wagoner)

PHYSICS 18N. Revolutions in Concepts of the Cosmos—Stanford Introductory Seminar. Preference to freshmen. Faculty led dialogue. Introduction to the evolution of our concept of the cosmos and its origin, from the Copernican heliocentric model of the solar system to our current view based on Hubble's discovery of expansion of the universe. Recent cosmological observations and the relevance to this topic of laboratory experiments in particle physics. One night of observations at the Stanford Observatory. Enrollment limited to 20 in one section. GER:2a

3 units, Spr (Wojcicki)

PHYSICS 50. Astronomy Laboratory and Observational Astronomy—Introduction to observational astronomy with emphasis on the use of optical telescopes. Observations of stars, nebulae, and galaxies are pursued during laboratory sessions with 16- and 24-inch telescopes at the Stanford Observatory. Lectures and analysis are descriptive; no calculations or previous physics required. Limited enrollment. Lab. GER:2a

3 units, Aut, Sum (Church, Staff)

PHYSICS 81Q. Lookback Time in Cosmology—Stanford Introductory Seminar. Preference to sophomores. The use of telescopes as time machines to see the history of the universe. Summary of the big bang, and galaxies and quasars at high redshift. How old is the universe? When did the first objects form? When were the elements created? What is the cosmic dark matter? Can we predict the future evolution of the cosmos? Discussion is at a semi-quantitative level: basic physics concepts are used without calculus. Directed reading, sample exercises, and, weather permitting, a term project observing distant galaxies and quasars at the Stanford Observatory. Prerequisites: elementary physics (21-25 or equivalent).

1 unit (Staff) not given 2003-04

PHYSICS 82Q. Expanding Cosmic Horizons—Stanford Introductory Seminar. Preference to sophomores. The history and structure of our cosmic environment. How recent advances in observations at various wavelengths are expanding the horizons of our knowledge. Possible topics: What are the properties of black holes? What is the nature, amount, and distribution of the dark matter which appears to dominate the universe? What is the geometry and fate of the universe? Prerequisite: freshman physics or equivalent.

1 unit (Staff) not given 2003-04

PHYSICS 85Q. Cosmology in the 21st Century—Stanford Introductory Seminar. Preference to sophomores. Current topics at the frontier of research in cosmology including dark matter, dark energy, the cosmic microwave background, inflation, matter-antimatter asymmetry, and the origin of the big bang.

1 unit, Spr (Thomas)

PHYSICS 100. Introduction to Observational and Laboratory Astronomy—Introduction to observational techniques in astronomy for physical science or engineering students. Emphasis is on the quantitative measurement of fundamental astronomical parameters such as distance, temperature, mass, composition of stars, galaxies, and quasars. Lecture and observation using the 0.4m and 0.6m telescopes at the Stanford Observatory. Limited enrollment. Prerequisites: one year of physics; prior or concurrent registration in 25, 65, or 70; and consent of instructor. GER:2a

4 units, Spr (Romani)

PHYSICS 160. Introduction to Stellar and Galactic Astrophysics—Physics of the sun. Evolution and death of stars. White dwarfs, novae, planetary nebulae, supernovae, neutron stars, pulsars, binary stars, x-ray stars, and black holes. Galactic structure: interstellar medium, molecular clouds, HI and HII regions, star formation and element abundances. Prerequisites: calculus and one year of college physics at the level of the 50 series or equivalent.

3 units, Win (Romani)

PHYSICS 161. Introduction to Extragalactic Astrophysics and Cosmology—Observations of the distances and compositions of objects on cosmic scales: galaxies, galaxy clusters, quasars, and diffuse matter at high redshift. Big bang cosmology, physical processes in the early universe, the origin of matter and the elements, inflation, and creation of structure in the universe. Observational evidence for dark matter and dark energy. Future of the universe. Prerequisites: calculus and one year of college physics at the level of the 50 series.

3 units, Spr (Petrosian)

PHYSICS 164. Planetary Systems: Dynamics and Origins—(Enroll in GES 222.)

3 units, Aut (Lissauer) alternate years, not given 2004-05

PHYSICS 169A,B,C. Independent Study in Astrophysics and Honors Thesis—Detailed study of a problem in astrophysics with one or more faculty members. While not all projects require three quarters, the sequence below suggests the format most projects are expected to follow. Projects may commence in Autumn, Winter, Spring, or Summer.

PHYSICS 169A. Independent Study in Astrophysics and Honors Thesis: Selection of the Problem—Selection of the problem to be studied and development of the theoretical apparatus or initial interpretation of the selected problem. Preparation of a detailed description of the problem and its background and a comprehensive discussion of the work planned in the subsequent two quarters.

1-9 units, Aut (Staff)

PHYSICS 169B. Independent Study in Astrophysics and Honors Thesis: Continuation of Project—Substantial completion of the required computations or data analysis for the research project selected.

1-9 units, Win (Staff)

PHYSICS 169C. Independent Study in Astrophysics and Honors Thesis: Completion of Project—Completion of research and writing of a detailed paper presenting methods used and results.

1-9 units, Spr (Staff)

PHYSICS

PHYSICS 11N. The Basic Rules of Nature—Stanford Introductory Seminar. Preference to freshmen. Physicists have developed successful descriptions of the basic behavior of matter on microscopic scales (inner space) and on scales characteristic of the universe as a whole (outer space). Despite these successes, deep mysteries remain. Elements of these successful descriptions including quantum mechanics, particle physics, and general relativity. Remaining mysteries and the leading approaches that physicists hope will unravel them including string theory and M theory. Discussions are semiquantitative. Term project paper. Prerequisite: high school physics or equivalent. GER:2a

3 units, Aut (Shenker)

PHYSICS 12N. The Physics of Time—Stanford Introductory Seminar. Preference to freshmen. The concept of time, its properties, and how it is measured. How the concept of time has evolved. The measurement of time, from the age of the universe, the Earth, and civilizations, to the shortest discernible instants. A technological history of the measurement of time from pendulums to atomic clocks; how improved measurements of time changed society and the concept of time in physics. Symmetry and the irreversibility of time. Preference to students concurrently enrolled in the 50 or 60 series. Recommended: strong mathematics and physics backgrounds. GER:2a

3 units, Spr (Chu)

PHYSICS 19. How Things Work: An Introduction to Physics—Examines familiar objects such as the microwave oven, refrigerator, and pop-up toaster, and uses them to present basic principles of physics in an approachable and understandable context. Emphasis on developing an intuitive picture. Make estimates of real quantities from simple calculations. Prerequisite: high school algebra and trigonometry. GER:2a

3 units, Aut (I. R. Fisher)

PHYSICS 21. Mechanics and Heat—For biology, social science, and premedical students. Introduction to Newtonian mechanics, fluid mechanics, theory of heat. Calculus is used as a language and developed as needed. Prerequisite: working knowledge of elementary algebra and trigonometry. GER:2a

3 units, Aut (Wojcicki)

PHYSICS 21S. Mechanics and Heat with laboratory—Equivalent to 21 and 22. GER:2a

4 units, Sum (G. Fisher)

PHYSICS 22. Mechanics and Heat Laboratory—Pre- or corequisite: 21.

1 unit, Aut (Staff)

PHYSICS 23. Electricity and Optics—Electric charges and currents, magnetism, induced currents; wave motion, interference, diffraction, geometrical optics. Prerequisite: 21. GER:2a

3 units, Win (Church)

PHYSICS 24. Electricity and Optics Laboratory—Pre- or corequisite: 23.

1 unit, Win (Staff)

PHYSICS 25. Modern Physics—Introduction to modern physics. Relativity, quantum mechanics, atomic theory, radioactivity, nuclear reactions, nuclear structure, high energy physics, elementary particles, astrophysics, stellar evolution, and the big bang. Prerequisite: 23 or consent of instructor. GER:2a

3 units, Spr (Linde)

PHYSICS 25S. Modern Physics with Laboratory—Equivalent to 25 and 26. GER:2a

4 units, Sum (G. Fisher)

PHYSICS 26. Modern Physics Laboratory—Pre- or corequisite: 25.

1 unit, Spr (Staff)

PHYSICS 28. Mechanics, Heat, and Electricity—For biology, social science, and premedical students. The sequence 28 and 29 fulfills, in ten weeks, the one-year college physics requirement with lab of most medical schools. Topics: Newtonian mechanics, fluid mechanics, theory of heat, electric charges, and currents. Calculus is used as a language and developed as needed. Prerequisite: working knowledge of elementary algebra and trigonometry. GER:2a

6 units, Sum (G. Fisher)

PHYSICS 29. Electricity and Magnetism, Optics, Modern Physics—Magnetism, induced currents; wave motion, optics; relativity, quantum mechanics, atomic theory, radioactivity, nuclear structure and reactions, elementary particles, astrophysics, and cosmology. Prerequisite: 28. GER:2a

6 units, Sum (G. Fisher)

PHYSICS 51. Light and Heat—Reflection and refraction, lenses and lens systems; polarization, interference, and diffraction; temperature, properties of matter, introduction to kinetic theory of matter. Prerequisites: high school physics or 53, and MATH 19 or 41, or consent of instructor. GER:2a

4 units, Aut (Osheroff)

PHYSICS 51N. Advanced Topics in Light and Heat—Stanford Introductory Seminar. Preference to freshmen. Expands on the subject matter presented in 51 to include optics and thermodynamics in our everyday lives, and applications in the research laboratory. Corequisite: 51N or advanced placement.

1 unit, Aut (Laughlin)

PHYSICS 52. Light and Heat Laboratory—(Formerly 48.) Pre- or corequisite: 51.

1 unit, Aut (Staff)

PHYSICS 53. Mechanics—Vectors, particle kinematics and dynamics, work, energy, momentum, angular momentum; conservation laws; rigid bodies; mechanical oscillations and waves. Discussions based on use of calculus. Corequisite: MATH 19 or 41, or consent of instructor. GER:2a

4 units, Win (Burchat)

PHYSICS 53N. Mechanics: Insights, Applications, and Advances—Stanford Introductory Seminar. Preference to freshmen. Possible topics include tidal forces, gyroscopic effects, fractal dimensions, and chaos. Enrollment limited to 20 students in one section. Corequisite: 53.

1 unit (Staff) not given 2003-04

PHYSICS 55. Electricity and Magnetism—Electrostatics, including fields, potentials, capacitors, and dielectrics. Steady state currents, and circuits with batteries and resistors. RC circuits. Time varying currents and fields, inductance, Maxwell's equations. Prerequisites: 53, and MATH 19 or 41. Corequisite: MATH 20 or 42, or consent of instructor. GER:2a

4 units, Spr (Michelson)

PHYSICS 55N. Understanding Electromagnetic Phenomena—Stanford Introductory Seminar. (Formerly 43N.) Preference to freshmen. Expands on the material presented in 55, including phenomena associated with electricity and magnetism, to allow students to connect the material in 55 with their world. Corequisite: 55 or advanced placement.

1 unit, Spr (Greven)

PHYSICS 56. Electricity and Magnetism Lab—(Formerly 46.) Pre- or corequisite: 55.

1 unit, Spr (Staff)

PHYSICS 59. Current Research Topics—Recommended for all prospective physics majors. Major areas of current research. Topics: fundamental particles, solid state physics, low temperature physics, biophysics, and astrophysics. Lectures by faculty and physicists with research interests in these fields.

1 unit, Aut (Cabrera)

PHYSICS 61,63,65. Advanced Freshman Physics—Recommended for students contemplating a major in Physics and other students interested in a more rigorous treatment of physics. The fundamental structure of classical physics including Newtonian mechanics, Lagrangian mechanics, special relativity, and electricity and magnetism; topics in heat and light in Spring Quarter. Lectures and small discussion sections. Diagnostic quiz in calculus and conceptual Newtonian mechanics at first meeting of 61 to help students decide if course is appropriate; instructor may suggest some students would benefit more from the 50 series. Prerequisites: high school physics and familiarity with calculus (differentiation and integration in one variable); prior or concurrent registration in MATH 42. 61, 63, 65 each satisfy GER:2a

PHYSICS 61. Advanced Freshman Physics: Mechanics

4 units, Aut (Goldhaber-Gordon)

PHYSICS 63. Advanced Freshman Physics: Electromagnetism

4 units, Win (Susskind)

PHYSICS 65. Advanced Freshman Physics: Thermodynamics and Optics

4 units, Spr (Susskind)

PHYSICS 61N. Mechanics: Insights, Applications, and Advances—Stanford Introductory Seminar. Preference to freshmen. Possible topics include tidal forces, gyroscopic effects, fractal dimensions, and introduction to chaos. Enrollment limited to 20 students in one section. Corequisite: 61.

1 unit, Aut (Gratta)

PHYSICS 63N. Applications of Electromagnetism—Stanford Introductory Seminar. Preference to freshmen. Material related to PHYSICS 63 at a more advanced level. Students participate in selecting topics. Enrollment limited to 20 students in one section. Corequisite: 63.

1 unit, Win (Thomas)

PHYSICS 64. Advanced Electromagnetism Laboratory—Experimental work in mechanics, electricity and magnetism. Corequisite 63.

1 unit, Win (Staff)

PHYSICS 67. Introduction to Laboratory Physics—Introduction to methods of experimental design, data collection and analysis, statistics, and curve fitting in a laboratory setting. Experiments drawn from electronics, optics, heat, and particle physics. Intended as preparation for Physics 105, 107, 108. Lecture plus laboratory format. Required for 60 series physics majors, recommended for 50 series students who intend to major in physics. Corequisite: 65 or 55.

2 units, Spr (G. Fisher)

PHYSICS 70. Modern Physics—Relativity, the experimental basis of quantum theory, Schrödinger equation, atomic structure, nuclear structure, high energy physics, elementary particles. Prerequisite: 50 or 60 series. Recommended: prior or concurrent registration in MATH 53 or 130. GER:2a

4 units, Aut (Kasevich)

PHYSICS 80N. The Technical Aspects of Photography—Stanford Introductory Seminar. Preference to freshmen. For those with some background in photography. How cameras record photographic images on film and electronically. The technical photographic processes which the photographer must understand in order to use cameras effectively. Camera types and their advantages, how lenses work and their limitations, camera shutters, light meters and the proper exposure of film, film types, depth of focus, control of the focal plane and perspective, and special strategies for macro and night photography. View cameras and range finder technical cameras. Students exploit the flexibility of these formats to take photographs around campus. Prerequisite: knowledge of elementary physics.

3 units, Spr (Osheroff)

PHYSICS 80Q. The Technical Aspects of Photography—Stanford Introductory Seminar. Preference to sophomores. Enrollment limited to 15.

3 units, Win (Osheroff)

PHYSICS 83N. Physics in the 21st Century—Stanford Introductory Seminar. Preference to freshmen. Current topics at the frontier of modern physics. Topics include subatomic particles and the standard model, symmetries in nature, extra dimensions of space, string theory, supersymmetry, the big bang theory of the origin of the universe, black holes, dark matter, and dark energy of the universe. Why does the sun shine; cosmology and inflation. GER:2a

3 units, Win (Dimopoulos)

PHYSICS 105,107,108. Intermediate Physics Laboratory Sequence—Sequence in experimental techniques required of all Physics majors.

PHYSICS 105. Intermediate Physics Laboratory I: Analog Electronics—Analog electronics, from Ohm's Law and passive circuits to transistor and op amp circuits, with an emphasis on developing practical circuit design skills to prepare undergraduates for laboratory research. Course culminates in a short design project. Minimal use of math and physics, no prior electronics experience assumed beyond introductory physics. Prerequisite: 55 or 63 or other introductory electricity and magnetism course.

3 units, Aut (Pam)

PHYSICS 107. Intermediate Physics Laboratory II: Experimental Techniques and Data Analysis—Experiments on lasers, Gaussian optics, and atom-light interaction, with emphasis on data and error analysis techniques. Students describe a subset of experiments in scientific paper format. Prerequisites: completion of 50 or 60 series, 70, and 105. Recommended: 130, prior or concurrent enrollment in 120. (WIM)

4 units, Win (Kasevich)

PHYSICS 108. Intermediate Physics Laboratory III: Project—Small student groups plan, design, build, and carry out a single experimental project in low-temperature physics. Prerequisites 105, 107.

3 units, Spr (Topinka)

PHYSICS 110. Intermediate Mechanics—The mechanics of systems of particles and rigid bodies. Newtonian mechanics; linear and nonlinear oscillations; Hamilton's principle, Lagrangian and Hamiltonian dynamics; central forces, planetary motion; collisions; non-inertial reference systems; rigid body dynamics; coupled oscillations; and introductory fluid mechanics oscillations. Prerequisites: 53 or 61, and MATH 53 or 130.

4 units, Spr (Gratta)

PHYSICS 112. Mathematical Methods of Physics—Theory of complex variables, complex functions, and complex analysis. Fourier series and Fourier transforms. Special functions such as Laguerre, Legendre, and Hermite polynomials, and Bessel functions. The uses of Green's functions. Covers material of MATH 106 and 132, most pertinent to Physics majors. Prerequisites: MATH 50 or 50H series, MATH 131.

4 units, Win (Shenker)

PHYSICS 113. Computational Physics—Introduction to numerical methods for solving problems in mechanics, electromagnetism, quantum mechanics, and statistical mechanics. Methods include numerical integration; solutions of ordinary and partial differential equations; solutions of the diffusion equation, Laplace's equation and Poisson's equation with relaxation methods; statistical methods including Monte Carlo techniques; matrix methods and eigenvalue problems. Short introduction to MatLab, used for class examples; class projects may be programmed in any language such as C. Prerequisites: 110, 121, and MATH 53 or 130. Previous programming experience not required.

4 units, Spr (Cabrera)

PHYSICS 120,121. Intermediate Electricity and Magnetism—Vector analysis, electrostatic fields, including multipole expansion; dielectrics. Special relativity and transformation between electric and magnetic fields. Maxwell's equations. Static magnetic fields, magnetic materials. Electromagnetic radiation, plane wave problems (free space, conductors and dielectric materials, boundaries). Dipole and quadrupole radiation. Wave guides and cavities. Prerequisites: 55 or 63; concurrent or prior registration in MATH 53 and 131 for PHYSICS 120 and 121, respectively. Recommended: concurrent or prior registration in MATH 112.

PHYSICS 120. *4 units, Win (Thomas)*
PHYSICS 121. *4 units, Spr (Shen)*

PHYSICS 130,131. Quantum Mechanics—The origins of quantum mechanics, wave mechanics, and the Schrödinger equation. Heisenberg's matrix formulation of quantum mechanics, solutions to one-dimensional systems, separation of variables and the solution to three-dimensional systems, the central field problem and angular momentum eigenstates, spin and the coupling of angular momentum, Fermi and Bose statistics, time-independent perturbation theory. Prerequisites: 70, 110; concurrent or prior registration in 120, 121, and MATH 131.

PHYSICS 130. *4 units, Aut (Kachru)*
PHYSICS 131. *4 units, Win (Kachru)*

PHYSICS 134. Advanced Topics in Quantum Mechanics—Variational principle, WKB approximation, time-dependent perturbatrion theory. Scattering theory: partial wave expansion, Born approximation. EPR paradox and Bell's inequality. Brief introduction to relativistic quantum mechanics. Prerequisites: 130, 131.

4 units, Spr (Burchat)

PHYSICS 152. Introduction to High Energy Physics—(Graduate students register for 252.) The standard model of particle physics. unified weak and electromagnetic interactions. Quantum chromodynamics and strong interactions. Flavor violating processes; grand unified theories; early cosmology and baryogenesis. Prerequisite: 121.

3 units, Win (Dimopoulos)

PHYSICS 170,171. Thermodynamics, Kinetic Theory and Statistical Mechanics—The derivation of laws of thermodynamics from basic postulates; the determination of the relationship between atomic substructure and macroscopic behavior of matter. Temperature; equations of state, heat, internal energy; entropy; reversibility; applications to various properties of matter; absolute zero and low-temperature phenomena. Distribution functions, transport phenomena, fluctuations, equilibrium between phases, phase changes, the partition function for classical and quantum systems, Bose-Einstein condensation, and the electron gas. Cooperative phenomena including ferromagnetism, the Ising model, and lattice gas. Irreversible processes. Prerequisites: 51 or 65, and MATH 53 or 130.

PHYSICS 170. *4 units, Aut (Kapitulnik)*
PHYSICS 171. *4 units, Win (Kapitulnik)*

PHYSICS 172. Physics of Solids I—Introduction to solid state physics. Crystal properties and the consequence of the periodic nature of solids. Electrons and phonons, elementary band theory, electrical and thermal transport. Semiconductor physics. Prerequisite: 170.

3 units, Win (I. R. Fisher)

PHYSICS 173. Magnetism and Long Range Order in Solids—(Enroll in APPPHYS 270.)

3 units, Spr (I. R. Fisher)

PHYSICS 173B. Concepts in Condensed Matter Physics—Introduction to advanced concepts in condensed matter physics using simple, archetypical examples. Topics include interaction and correlation, emergent order and symmetry breaking, new states of matter, pattern formation, and nonlinear dynamics in material systems. For students with a strong physics interest who have completed a basic introductory course in solid state or condensed matter physics.

1 unit, Spr (Beasley)

PHYSICS 181. Introduction to Modern Optics—(Enroll in EE 268.)

3 units, Aut (Hesselink) alternate years, not given 2004-05

PHYSICS 190. Independent Study—Undergraduate research in experimental or theoretical physics under the supervision of a faculty member. Prerequisites: superior work as an undergraduate physics major; and approval of the instructor.

1-9 units, Aut, Win, Spr, Sum (Staff)

PHYSICS 192. Introductory Biophysics—(Enroll in APPPHYS 192.)

3 units, Spr (Doniach) alternate years, not given 2004-05

PHYSICS 199. Guest Lecture Series: Statistics for Physicists—(Graduate students register for 299.) One-time offering. Statistical ideas and techniques needed by experimental physicists from the undergraduate laboratory to graduate research. Basic concepts, distributions, definitions of probability, maximum likelihood and other estimation techniques, fitting and goodness-of-fit, and confidence intervals. Prerequisite: MATH 42.
3 units, Win (Barlow)

PHYSICS 204. Advanced Seminar in Theoretical Physics—Topics of recent interest in theoretical physics: Bose-Einstein condensation of atoms, high Tc superconductivity of cuprates, quantized Hall effect, quantum and classical chaos, superfluidity in 2D, protein folding. Work in the seminar may provide a basis for an honors project in theoretical physics. Prerequisite: 134 or consent of instructor.
3 units, Aut (Doniach)

PHYSICS 205. Undergraduate Honors Research—Experimental or theoretical project and thesis in Physics under supervision of a faculty member. Planning of the thesis project should begin no later than middle of the junior year. Successful completion of an honors thesis leads to graduation with departmental honors. Prerequisites: superior work in Physics as an undergraduate major and approval of the honors adviser.
1-12 units, Aut, Win, Spr, Sum (Staff)

PHYSICS 207. Laboratory Electronics—(Enroll in APPPHYS 207.)
3 units, Spr (Fox)

PHYSICS 208. Laboratory Electronics—(Enroll in APPPHYS 208.)
3 units (Fox) alternate years, given 2004-05

GRADUATE

PHYSICS 210. Advanced Particle Mechanics—The Lagrangian and Hamiltonian dynamics of particles. Beyond small oscillations. Phase portraits, Hamilton-Jacoby theory, action-angle variables, adiabatic invariance. Nonlinear dynamical systems, continuous and discrete. Behavior near the fixed points, stability of solutions, attractors, chaotic motion. Transition to continuum mechanics. Prerequisite: 110 or equivalent.
3 units, Aut (Kallosh)

PHYSICS 211. Continuum Mechanics—Elasticity, fluids, turbulence, waves, gas dynamics, shocks, and MHD plasmas. Examples from everyday phenomena, geophysics, and astrophysics.
3 units, Win (Blandford)

PHYSICS 212. Statistical Mechanics—Kinetic theory; evolution of distribution function, transport coefficients. Principles of statistical mechanics; ensembles, statistical equilibrium. Thermodynamic functions, ideal and near-ideal gases, solids. Fluctuations, noise, and irreversible thermodynamics. Phase transitions and cooperative phenomena. Prerequisites: 171, 231.
3 units, Spr (Thomas)

PHYSICS 215. Numerical Methods for Physicists and Engineers—(Enroll in APPPHYS 215.)
3 units, Aut (Moler) alternate years, not given 2004-05

PHYSICS 216. Back of the Envelope Physics—Techniques to make order-of-magnitude estimates of physical effects. Goal is to sharpen physical intuition and promote a synthesis of physics through the application of undergraduate physics to problems, some not included in the standard curriculum. Techniques such as scaling and dimensional analysis. Applications include properties of materials, geophysics, astrophysics and cosmology, biomechanics, and particle physics. Prerequisites: undergraduate mechanics, statistical mechanics, electricity and magnetism, and quantum mechanics.
3 units, Aut (Wagoner)

PHYSICS 220,221. Classical Electrodynamics—Electrostatics and magnetostatics: conductors and dielectrics, magnetic media, electric and magnetic forces, and energy. Maxwell's equations: electromagnetic waves, Poynting's theorem, electromagnetic properties of matter, dispersion relations, wave guides and cavities, magnetohydrodynamics. Special relativity: Lorentz transformations, covariant, equations of electrodynamics and mechanics, Lagrangian formulation, Noether's theorem and conservation laws. Radiation: dipole and quadrupole radiation, electromagnetic scattering and diffraction, the optical theorem, Liénard-Wiechert potentials, relativistic Larmor's formula, frequency and angular distribution of radiation, synchrotron radiation. Energy losses in matter: Bohr's formula, Cherenkov radiation, bremsstrahlung and screening effects, transition radiation. Prerequisites: 121 or equivalent; 210 or MATH 106 and 132.

PHYSICS 220. *3 units, Win (Wagoner)*
PHYSICS 221. *3 units, Spr (Laughlin)*

PHYSICS 223. Applied Quantum Mechanics II—(Enroll in EE 223.)
3 units, Win (Vuckovic)

PHYSICS 226. Physics of Quantum Information—(Enroll in APPPHYS 226.)
3 units (Yamamoto) alternate years, given 2004-05

PHYSICS 230,231,232. Quantum Mechanics—Prerequisites: Quantum mechanics at the undergraduate level and a strong course on differential equations.

PHYSICS 230. Quantum Mechanics—Fundamental concepts. Introduction to Hilbert spaces and Dirac's notation. Postulates are applied to simple systems, including those with periodic structure. Symmetry operations and gauge transformation. The concept of propagators and path integral quantization. Problems related to measurement theory. The quantum theory of angular momenta and central potential problems (hydrogen, quarkonium).
3 units, Aut (Chu)

PHYSICS 231. Quantum Mechanics—Basis for higher level courses on atomic physics, optics, spectroscopy, and particle physics. Wigner-Eckart theorem and addition of angular momenta. Approximation methods for time-independent and time-dependent perturbations. Semiclassical and quantum theory of radiation, second quantization of radiation and matter fields. Systems of identical particles and many electron atoms.
3 units, Win (Chu)

PHYSICS 232. Quantum Mechanics—Special topics. Elementary scattering theory (Born approximation, partial wave analyses, resonance scattering). S-matrix formalism. Relativistic single-particle equations. Dirac equation applied to central potentials, relativistic corrections, and nonrelativistic limits.
3 units, Spr (Brodsky)

PHYSICS 252. Introduction to High Energy Physics—See 152.
3 units, Win (Dimopoulos)

PHYSICS 260. Introduction to Astrophysics and Cosmology—The basic properties of stars, galaxies, and the universe. Physical processes for production of radiation from cosmic sources. The observations of cosmic microwave background radiation and consequences for the formation, structure, and evolution of the universe. Models of the early universe, nature of dark matter and dark energy, inflation, and the relation between particle physics and cosmology. Prerequisites: 121, 171.
3 units, Aut (Petrosian) alternate years, not given 2004-05

PHYSICS 262. Introduction to Gravitation—Review of special relativity. An introduction to general relativity. Curvature, energy-momentum tensor, Einstein field equations. Newtonian limit of general relativity. Introduction to black holes, gravitational waves, cosmology. Prerequisites: 121 or other courses including special relativity.
3 units, Spr (Kallosh)

PHYSICS 272. Solid State Physics I—(Enroll in APPPHYS 272.)
3 units, Win (Manoharan)

PHYSICS 273. Solid State Physics II—(Enroll in APPPHYS 273.)
3 units, Spr (Manoharan)

PHYSICS 275. Electrons in Nanostructures—The behavior of electrons in metals or semiconductors at length scales below 1 micron, smaller than familiar macroscopic objects but larger than atoms. Ballistic transport, Coulomb blockade, localization, quantum mechanical interference, and persistent currents. Topics may include quantum Hall systems, spin transport, spin-orbit coupling in nanostructures, magnetic tunnel junctions, Kondo systems, and 1-dimensional systems. Readings focus on the experimental research literature, and recent texts and reviews. Prerequisite: undergraduate-level familiarity with quantum mechanics and solid state physics.

3 units, Win (Goldhaber-Gordon) alternate years, not given 2004-05

PHYSICS 290. Research Activities at Stanford—Required of all first-year physics graduate students and strongly suggested for junior physics majors for 1 unit; no registration needed for graduate students. Review of research activities in the department and elsewhere at Stanford at a level suitable for entering graduate students.

1-3 units, Aut (Zhang)

PHYSICS 291. Practical Training—Opportunity for practical training in industrial labs. Arranged by student with the research adviser's approval. A brief summary of activities is required, approved by the research adviser.

3 units, Sum (Staff)

PHYSICS 293. Literature of Physics—Intensive study of the literature of any special topic. Preparation, presentation of reports. If taken under the supervision of a faculty member outside the department, approval of the Physics chair required. Prerequisites: 25 units of college physics, consent of instructor.

1-15 units, Aut, Win, Spr, Sum (Staff)

PHYSICS 294. Teaching of Physics Seminar—Required of all teaching assistants in Physics concurrent with the first quarter of a teaching appointment; registration not required. Techniques of teaching physics by means of weekly seminars/discussions, simulated teaching situations, and evaluation of in-class teaching performance.

1 unit, Aut, Win, Spr (Pam)

PHYSICS 299. Guest Lecture Series: Statistics for Physicists—(Graduate section; see 199.)

3 units, Win (Barlow)

PHYSICS 301. Astrophysics Laboratory—Combined seminar/lab investigating astronomical observational techniques and physical models of astronomical objects. Observational component uses the 24-inch telescope at the Stanford Observatory and ancillary photometric and spectroscopic instrumentation. Emphasis is on spectroscopic and photometric observation of main sequence, post-main sequence, and variable stars. Term project developing observational equipment or software. Limited enrollment. Prerequisite: consent of instructor.

3 units, Spr (Romani)

PHYSICS 312. Basic Plasma Physics—For the nonspecialist who needs a working knowledge of plasma physics for space science, astrophysics, fusion, or laser applications. Topics: orbit theory, the Boltzmann equation, fluid equations, MHD waves and instabilities, EM waves, the Vlasov theory of ES waves and instabilities including Landau damping and quasilinear theory, the Fokker-Planck equation, and relaxation processes. Advanced topics in resistive instabilities and particle acceleration. Prerequisite: 210 and 220, or consent of instructor.

3 units (Staff) not given 2003-04

PHYSICS 315. Methods in Computational Biology—(Enroll in APPPHYS 315.)

3 units, Win (Doniach) alternate years, not given 2004-05

PHYSICS 320. Quantum Optics and Selected Topics in Atomic Physics—Quantization of the electromagnetic field, photon states, and vacuum fluctuations and atomic transitions of real atoms. Two-level atoms, the Optical Bloch Equations, dressed states, coherent transients, resonance fluorescence, laser cooling and trapping of atoms and ions, tests of quantum mechanics and Bell's Theorem, photon statistics, coherence, antibunching, squeezed states, and parity non-conservation and time-reversal invariance tests in atomic physics. Offered occasionally.

3 units (Staff) not given 2003-04

PHYSICS 321. Laser Spectroscopy—Theoretical concepts and experimental techniques of modern laser spectroscopy. Absorption, dispersion, Kramers-Kronig relations, line-shapes. Classical and laser linear spectroscopy. Semiclassical theory of laser atom interaction: time-dependent perturbation theory, density matrix, optical Bloch equations, coherent pulse propagation, multiphoton transitions. High-resolution nonlinear laser spectroscopy: saturation spectroscopy, polarization spectroscopy, two-photon and multiphoton spectroscopy, optical Ramsey spectroscopy. Semiclassical theory of the laser. Phase conjugation. Four-wave mixing, harmonic generation. Coherent Raman spectroscopy, quantum beats, ultra-sensitive detection. Offered occasionally. Prerequisite: 230. Recommended: 231.

3 units (Staff) not given 2003-04

PHYSICS 323. Laser Cooling and Trapping—The fundamental principles of laser cooling and atom trapping. The general treatment of optical forces on atoms, the various forms of laser cooling, atom optics and atom interferometry, ultra-cold collisions, and an introduction to Bose condensation of dilute gases. Emphasis is on the development of the general formalisms currently used to treat these topics. Applications of the cooling and trapping techniques: atomic clocks, internal sensors, measurements that address high-energy physics questions, studies of many-body effects, polymer science, and biology. Prerequisite: 231 or equivalent.

3 units, Spr (Kasevich)

PHYSICS 324. Introduction to Accelerator Physics—(Enroll in APPHYS 324.)

3 units, Aut (Siemann) alternate years, not given 2004-05

PHYSICS 330,331,332. Quantum Field Theory—Introduction to the concepts and methods of quantum field theory. Prerequisites: 210, 221, 232.

PHYSICS 330. Quantum Field Theory—Quantization of scalar and Dirac fields. Feynman diagrams. Quantum electrodynamics. Elementary electrodynamic processes: Compton scattering, e+e- annihilation. Loop diagrams and electron (g-2). Soft photons and infrared divergences.

3 units, Aut (Peskin)

PHYSICS 331. Quantum Field Theory—Functional integral methods, renormalization, Ward Identities, renormalization group, perturbation theory anomalies.

3 units, Win (Kallosh)

PHYSICS 332. Quantum Field Theory—Local gauge invariance, Yang-Mills fields, spontaneous symmetry breaking and the Higgs mechanism, quantization of Yang-Mills fields, asymptotic freedom. Quantum chromodynamics.

3 units, Spr (Silverstein)

PHYSICS 351,352. Elementary Particle Physics—The phenomena of elementary particle interactions and their theoretical interpretation. Offered occasionally. Prerequisite: 330.

PHYSICS 351. Elementary Particle Physics: Introduction to the Standard Model—Theory of electroweak interactions, electroweak unification, neutral flavor conservation, GIM mechanism. Theory of strong interactions, QCD confinement. Specialized topics chosen by the instructor.

3 units (Staff) not given 2003-04

PHYSICS 352. Neutrino Physics: Intrinsic Properties of Neutrinos—Neutrino masses and mixing. Kinematics tests for neutrino masses. Neutrino interactions, the number of light neutrino species. Solar and atmospheric neutrino anomalies. Artificial neutrino sources: reactors and particle accelerators. Majorana and Dirac neutrinos. Double-beta decay. Neutrinos in supernovae. Relic neutrinos. Neutrino telescopes.

3 units, Win (Gratta)

PHYSICS 360. Physics of Astrophysics—Theoretical concepts and tools for modern astrophysics. Radiation transfer equations; emission, scattering, and absorption mechanisms: Compton, synchrotron and Bremsstrahlung processes; photoionization and line emission. Equations of state of ideal, interacting, and degenerate gasses. Application to astrophysical sources such as HII regions, supernova remnants, cluster of galaxies, and compact sources such as accretion disks, X-ray, gamma-ray, and radio sources. Prerequisites: 121, 171 or equivalent.
3 units, Aut (Madejski) alternate years, not given 2004-05

PHYSICS 361. Stellar and Galactic Astrophysics—Basic astronomical data on stars, star clusters, interstellar medium, and the Milky Way galaxy. Basic theory of stellar structure; hydrostatic equilibrium, radiation balance, and energy production. Stellar formation, Jean's mass, and protostars. Evolution of stars to the main sequence and beyond to red giants, white dwarfs, neutron stars, and black holes. Structure of the Milky Way; the disk and spiral arms, central bulge or bar, black hole, the halo, and mass of the galaxy. Prerequisites: 221, and 260 or 360.
3 units (Staff) not given 2003-04

PHYSICS 362. Advanced Extragalactic Astrophysics and Cosmology—Basic observational data on the content and activities of galaxies, the content of the universe, the cosmic microwave background radiation, gravitational lensing, and dark matter in the universe. Models of the origin, structure, and evolution of the universe based on the theory of general relativity. Test of the models and the nature of dark matter and dark energy. Physics of the early universe, inflation, baryosynthesis, nucleosynthesis, and galaxy formation. Prerequisites: 210, 211, 260 or 360.
3 units, Win (Petrosian) alternate years, not given 2004-05

PHYSICS 363. Solar and Solar-Terrestrial Physics—Structure, mechanisms, and properties of the Sun's interior and atmosphere. Tools for solar observations; magnetic fields and polarimetry. Solar oscillations and helioseismology. Differential rotation and turbulent convection. Solar MHD, Alfven and magneto-acoustic waves. Solar cycle and dynamo. Magnetic energy release, reconnection, particle acceleration. Solar activity, sunspots, flares, coronal mass ejections; UV, X-ray, and high-energy particle emissions. The interaction of the solar wind with Earth's magnetosphere and its terrestrial effects; space weather. Prerequisite: 221 or equivalent.
3 units, Spr (Kosovichev)

PHYSICS 364. Advanced Gravitation—Fundamental principles and experiments. Methods for solving Einstein equations. Penrose diagrams, singularities, black holes, and thermodynamics. Charged and rotating black holes, Hawking radiation. Anti de Sitter and de Sitter spaces in applications to high energy physics and cosmology. Topics in general relativity, astrophysics, and high-energy physics. Prerequisites: 220, 221, and 262, or an equivalent introduction to general relativity.
3 units (Staff) not given 2003-04

PHYSICS 370. Theory of Many-Particle Systems—Application of quantum field theory to the nonrelativistic, many-body problem, including methods of temperature-dependent Green's functions and canonical transformations. Theory of finite-temperature, interacting Bose and Fermi systems with applications to superfluidity, superconductivity, and electron gas. Offered occasionally. Prerequisite: 232.
3 units, Aut (Zhang)

PHYSICS 372. Condensed Matter Theory I—(Enroll in APPPHYS 372.)
3 units (Zhang) not given 2003-04

PHYSICS 373. Condensed Matter Theory II—(Enroll in APPPHYS 373.)
3 units (Zhang) not given 2003-04

PHYSICS 376. Superfluidity and Superconductivity—Introduction to superfluid He: two-fluid model, phonons, and rotons, Feynman description, vortices, Bogoliubov theory. Phenomenology of superconductors: London description, Ginzburg-Landau model, type-I vs. type-II materials, Josephson effects, thin films, Kosterlitz-Thouless behavior, electron-phonon coupling. BCS theory: bulk systems, tunneling, strong-coupling materials, dirty and gapless superconductivity, fluctuation effects, Ginzburg criterion. Offered occasionally. Recommended: APPPHYS 272, 273, or equivalents.
3 units, Win (Laughlin)

PHYSICS 377. Literature of Condensed Matter Physics—Review of key discoveries in condensed matter physics in the past 15 years, with emphasis on experiment. Topics: sliding charge density waves in layer compounds, the first pressure-induced Mott transition and organic superconductor, the discovery of superfluid 3He, quasicrystals, the Sharvin effect, the Quantum Hall effect, and reentrant superconductivity. Journal club format with presentations by students on assigned topics. Offered occasionally.
3 units (Staff) not given 2003-04

PHYSICS 383. Introduction to Atomic Processes—(Enroll in APPPHYS 383.)
3 units, Aut (Harris) alternate years, not given 2004-05

PHYSICS 387. Quantum Optics and Measurements—(Enroll in APPPHYS 387.)
3 units, Win (Yamamoto) alternate years, not given 2004-05

PHYSICS 388. Mesoscopic Physics and Nanostructures—(Enroll in APPPHYS 388.)
3 units, Spr (Yamamoto) alternate years, not given 2004-05

PHYSICS 392. Topics in Molecular Biophysics—(Enroll in APPPHYS 392.)
3 units (Doniach) alternate years, given 2004-05

PHYSICS 450,451,452. Theoretical Physics of Particles and Fields—Advanced topics in theoretical high-energy physics. Topics change by quarter and year to provide a background in all areas of current theoretical research. Prerequisite: 332.

PHYSICS 450. Introduction to String Theory—Physics beyond the standard model. Gauge hierarchy problem. The supersymmetric standard model. Theories with large new dimensions and TeV-strings; the cosmological constant problem and recent approaches. Anthropic or multiverse approach to fundamental problems.
3 units, Aut (Dimopoulos)

PHYSICS 451. Particle Physics and Inflationary Cosmology—The standard big bang theory, its successes and problems. The general idea of inflationary cosmology and its various versions: old inflation, new inflation, chaotic inflation, hybrid inflation. Reheating of the universe and creation of matter after inflation. The theory of density perturbations, large-scale structure formation, and anisotropy of cosmic microwave background radiation. Eternal inflation and the global structure of the universe. Anthropic principle, the cosmological constant problem and dark energy. Towards inflation in string theory and brane cosmology.
3 units, Win (Linde)

PHYSICS 452. Behind the Horizon—What current understanding of quantum gravity and string/M theory says about physics behind horizons. Goal is to develop areas for future research.
3 units, Spr (Shenker)

PHYSICS 459. Frontiers in Interdisciplinary Biosciences—(Cross-listed in multiple departments in the schools of Humanities and Sciences, Engineering, and Medicine. Students should enroll through their affiliated department; otherwise enroll in CHEMENG 459.) See CHEMENG 459 or http://biox.stanford.edu/chemeng_index.html for description.
1 unit, Aut, Win, Spr (Robertson)

PHYSICS 463. Special Topics in Astrophysics: Experimental Cosmology—Content varies depending on the interests of staff and students. This year, topics include measurements of fluctuations in the cosmic microwave background, large-scale structure in the distributions of galaxies, the magnitude-redshift relation of Type 1a supernovae, the cosmic shear produced by weak gravitational lensing, and the mass and redshift distribution of clusters of galaxies. Theoretical framework underlying these techniques and experimental issues that limit such measurements.

3 units, Spr (Kahn)

PHYSICS 473A. Condensed Matter Physics—(Enroll in APPPHYS 473A.)

2 units, Spr (Greven)

PHYSICS 473B. Survey of Recent Progresses in Condensed Matter Physics—(Enroll in APPPHYS 473B.)

3 units, Win (Shen)

PHYSICS 473C. Physics of Disordered Systems—(Enroll in APPPHYS 473C.)

3 units, Spr (Kapitulnik)

PHYSICS 490. Research—Open only to Physics graduate students, with consent of instructor. Work is in experimental or theoretical problems in research, as distinguished from independent study of a non-research character in 190 and 293.

1-15 units, Aut, Win, Spr, Sum (Staff)

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