PHYSICS

Courses offered by the Department of Physics are listed under the subject code PHYSICS on the Stanford Bulletin's ExploreCourses web site.

Mission of the Undergraduate Program in Physics

The mission of the undergraduate program in Physics is to provide students with a strong foundation in both classical and modern physics. The goal of the program is to develop both quantitative problem solving skills and the ability to conceive experiments and analyze and interpret data. These abilities are acquired through both course work and opportunities to conduct independent research. The program prepares students for careers in fields that benefit from quantitative and analytical thinking, including physics, engineering, teaching, medicine, law, science writing, and science policy, in government or the private sector. In some cases, the path to this career will be through an advanced degree in physics or a professional program.

Learning Outcomes (Undergraduate)

Students develop an understanding of the fundamental laws that govern the universe, and a strong foundation of mathematical, analytical, laboratory, and written communication skills. They will also be presented with opportunities for learning through research. Upon completion of the Physics degree, students should have acquired the following knowledge and skills:

1. a thorough quantitative and conceptual understanding of the core areas of physics, including mechanics, electricity and magnetism, thermodynamics, statistical physics, and quantum mechanics, at a level compatible with admission to graduate programs in physics at peer institutions.
2. the ability to analyze and interpret quantitative results, both in the core areas of physics and in complex problems that cross multiple core areas.
3. the ability to apply the principles of physics to solve new and unfamiliar problems. This ability is often described as "thinking like a physicist."
4. the ability to use contemporary experimental apparatus and analysis tools to acquire, analyze and interpret scientific data.
5. the ability to communicate scientific results effectively in written papers and presentations or posters.

Course Work

The 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 also consult the "Astronomy Program (http://exploredegrees.stanford.edu/schoolofhumanitiesandsciences/astronomy)" 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, including the conception, design, and fabrication of laboratory equipment. Undergraduates are also encouraged to participate in research; most can do this through the senior thesis and/or the summer research program.

The study of physics is undertaken by three principal groups 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 careers in physics or related fields, including teaching and research in colleges and universities, research in federally funded laboratories and industry, and jobs in technical areas. Physics courses numbered below 100 are intended to serve all three of these groups. The courses numbered above 100 mainly meet the needs of the third group, but also of some students majoring in other branches of science and engineering.

Entry-Level Sequences in Physics

The Department of Physics offers three year-long, entry-level physics sequences, the PHYSICS 20, 40, and 60 series. The first of these (the 20 series) is non-calculus-based, and is intended primarily for those who are majoring in biology. Students with AP Physics credit, particularly those who are considering research careers, may wish to consider taking the PHYSICS 40 series, rather than using AP placement. These introductory courses provide a depth and emphasis on problem solving that has significant value in biological research, given today's considerable physics-based technology.

For those intending to major in engineering or the physical sciences, or simply wanting a stronger background in physics, the department offers the PHYSICS 40 and 60 series. Either of these satisfies the entry-level physics requirements of any Stanford major. The 60 series is intended for those who have already taken a Physics course at the level of the 40 series, or at least have a strong background in mechanics, some background in electricity and magnetism, and a strong background in calculus.

The PHYSICS 40 series begins with PHYSICS 41 Mechanics in Winter Quarter, PHYSICS 43 Electricity and Magnetism in Spring Quarter, and PHYSICS 45 Light and Heat in Autumn Quarter. While it is recommended that most students begin the sequence with PHYSICS 41 in Winter Quarter, those who have had strong physics preparation in high school (such as a score of at least 4 on the Physics AP C exam) may start the sequence with PHYSICS 45 in Autumn Quarter.

PHYSICS 41E and PHYSICS 43A are optional 1 unit companion courses to PHYSICS 41 and PHYSICS 43 respectively. They provide additional problem solving for students with less preparation in math and physics.

The Physics Tutoring Center offers help to students in the Entry-Level courses. It is staffed Monday through Friday.

Entry-Level Course List

One course from the following is recommended for the humanities or social science student who wishes to become familiar with the methodology and content of modern physics:

		Units
PHYSICS 15	Stars and Planets in a Habitable Universe	3
PHYSICS 16	The Origin and Development of the Cosmos	3
PHYSICS 17	Black Holes and Extreme Astrophysics	3
PHYSICS 19	How Things Work: An Introduction to Physics (not offered 2017-18)	3

The 20 series (below) is recommended for general students and for students preparing for medicine or biology:

		Units
PHYSICS 21	Mechanics, Fluids, and Heat	4
PHYSICS 22	Mechanics, Fluids, and Heat Laboratory	1
PHYSICS 23	Electricity, Magnetism, and Optics	4
PHYSICS 24	Electricity, Magnetism, and Optics Laboratory	1
PHYSICS 25	Modern Physics	4
PHYSICS 26	Modern Physics Laboratory	1

The 40 series (below) is for students majoring in engineering, chemistry, earth sciences, mathematics, or physics:

		Units
PHYSICS 41	Mechanics	4
PHYSICS 42	Classical Mechanics Laboratory	1
PHYSICS 43	Electricity and Magnetism	4
PHYSICS 44	Electricity and Magnetism Lab	1
PHYSICS 45	Light and Heat	4
PHYSICS 46	Light and Heat Laboratory	1

The 60 series (below), or advanced freshman series, is for students who have had strong preparation in physics and calculus in high school. Students who have had the appropriate background and wish to major in physics should take this introductory series:

		Units
PHYSICS 61	Mechanics and Special Relativity	4
PHYSICS 62	Mechanics Laboratory	1
PHYSICS 63	Electricity, Magnetism, and Waves	4
PHYSICS 64	Electricity, Magnetism and Waves Laboratory	1
PHYSICS 65	Quantum and Thermal Physics	4
PHYSICS 67	Introduction to Laboratory Physics	2

Physics Placement Diagnostic

Students who are planning to take either of the calculus-based sequences (PHYSICS 40 or 60 sequence) are advised to take the Physics Placement Diagnostic (https://web.stanford.edu/group/canvas/cgi-bin/www/discovery.php) that is offered twice at the beginning of the school year: during New Student Orientation and on the evening of the first day of instruction in the Autumn Quarter. Advice will be sent to each student with guidance on placement in the 40 or 60 sequence. See the department's Placement Diagnostic (https://physics.stanford.edu/academics/undergraduate-students/placement-diagnostic) page for details. Students who do not plan to take the 40 or 60 sequence do not need to take the Placement Diagnostic.

Graduate Programs in Physics

Graduate students find opportunities for research in many areas of Physics. Faculty advisers are drawn from many departments, including, but not limited to Physics, Particle Physics and Astrophysics at SLAC, Photon Science at SLAC, Materials Science and Engineering, Electrical Engineering, and Biology.

The number of graduate students admitted to the Department of Physics is strictly limited. Students should submit applications by Tuesday, December 18, 2018 for matriculation the following Autumn Quarter. Graduate students may normally enter the department only at the beginning of Autumn Quarter.

Learning Outcomes (Graduate)

The purpose of the master's program is to further develop knowledge and skills in physics and to prepare students for a professional career or doctoral studies. This is achieved through completion of courses, in the primary field as well as related areas, and experience with independent work and specialization.

The Ph.D. is conferred upon candidates who have demonstrated substantial scholarship and the ability to conduct independent research and analysis using the tools of Physics. Through completion of advanced course work and rigorous skills training, the doctoral program prepares students to make original contributions to the knowledge of physics and to interpret and present the results of such research.

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. More detailed information is provided with the offer of admission.

Laboratories and Institutes

The Russell H. Varian Laboratory of Physics, the Physics and Astrophysics Building, the W. W. Hansen Experimental Physics Laboratory (HEPL), the E. L. Ginzton Laboratory, the Center for Nanoscale Science and Engineering and the Geballe Laboratory for Advanced Materials (GLAM) together house a range of physics activities from general courses through advanced research. 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 materials community on campus with a range of characterization tools: it is the site for the Stanford Nanocharacterization Lab (SNL) and the NSF-sponsored Center for Probing the Nanoscale (CPN). The SLAC National Accelerator Laboratory is just a few miles from the Varian Laboratory. SLAC is a national laboratory funded by the Offices of Basic Energy Sciences and High Energy Physics of the Department of Energy. Scientists at SLAC conduct research in photon science, accelerator physics, particle physics, astrophysics and cosmology. The laboratory hosts a two-mile-long linear accelerator that can accelerate electrons and positrons. The Stanford Synchrotron Radiation Light Source (SSRL) uses intense x-ray beams produced with a storage ring on the SLAC site. The Linac Coherent Light Source (LCLS), completed in 2009, is the world's first x-ray free-electron laser and has opened new avenues of research in ultra-fast photon science.

The Kavli Institute for Particle Astrophysics and Cosmology (KIPAC), formed jointly with the SLAC National Accelerator Laboratory, provides a focus for theoretical, computational, observational, and instrumental research programs. A wide range of research areas in particle astrophysics and cosmology are investigated by students, postdocs, research staff and faculty. The two major projects with which KIPAC is heavily involved are the Fermi Gamma-Ray Space Telescope (FGST) and the Large Synoptic Survey Telescope (LSST). KIPAC members also participate fully in the Cryogenic Dark Matter Search (CDMS), the Solar Dynamics Observatory (SDO), the EXO-200 double beta decay experiment, the Dark Energy Survey (DES), the NuSTAR and Astro-H X-ray satellites, and several cosmic microwave background experiments (BICEP, KECK, QUIET and POLAR-1).

The Ginzton Laboratory, HEPL, GLAM, KIPAC, SLAC, and SSRL are listed in the "Centers, Laboratories, and Institutes (http://exploredegrees.stanford.edu/centerslaboratoriesandinstitutes/#researchtext)" 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, an interdisciplinary biology, medicine, and bioengineering laboratory.

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

Physics Course Numbering System

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

Digit	Description
100	intermediate and advanced 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:

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

Bachelor of Science in Physics

To help in deciding which introductory sequence is most suitable, students considering a major in Physics may contact the undergraduate program coordinator (elva@stanford.edu) to arrange an advising appointment. Also see the Physics Placement Diagnostic web site (https://physics.stanford.edu/undergraduate-program/placement-test). Although it is possible to complete the Physics major in three years, students who contemplate starting the major during sophomore year should make an advising appointment to map out their schedule. Students who have had previous college-level courses (including EPGY) should make an advising appointment for placement and possible transfer credit. For advanced placement advice, see the Registrar's web site (http://studentaffairs.stanford.edu/registrar/students/ap).

Prospective Physics majors are advised to take PHYSICS 59 Frontiers of Physics Research in their freshman or sophomore year.

Required Courses for Majors

All courses for the Physics major must be taken for a letter grade, and a grade of 'C-' or better must be received for all units applied toward the major.

For sample schedules illustrating how to complete the Physics major, see the Department of Physics (https://physics.stanford.edu/undergraduate-program/four-year-plans) web site.

		Units
Introductory Sequence		16-20
Complete either the 40 Series or the 60 Series		
40 Series (19-20 units):		
PHYSICS 41	Mechanics	
PHYSICS 42	Classical Mechanics Laboratory	
PHYSICS 43	Electricity and Magnetism	
PHYSICS 44	Electricity and Magnetism Lab	
or PHYSICS 67	Introduction to Laboratory Physics	
PHYSICS 45	Light and Heat	
PHYSICS 46	Light and Heat Laboratory	
PHYSICS 70	Foundations of Modern Physics	
60 Series (16 units):		
PHYSICS 61	Mechanics and Special Relativity	
PHYSICS 62	Mechanics Laboratory	
PHYSICS 63	Electricity, Magnetism, and Waves	
PHYSICS 64	Electricity, Magnetism and Waves Laboratory	
PHYSICS 65	Quantum and Thermal Physics	
PHYSICS 67	Introduction to Laboratory Physics	
Required Math Courses (21-24 units)		
MATH 51	Linear Algebra, Multivariable Calculus, and Modern Applications [3]	5
or MATH 61CM	Modern Mathematics: Continuous Methods	
MATH 52	Integral Calculus of Several Variables [3]	5
or MATH 62CM	Modern Mathematics: Continuous Methods	
MATH 53	Ordinary Differential Equations with Linear Algebra [3]	5
or MATH 63CM	Modern Mathematics: Continuous Methods	
PHYSICS 111	Partial Differential Equations of Mathematical Physics	4
or MATH 131P	Partial Differential Equations	
or MATH 173	Theory of Partial Differential Equations	
Plus one advanced mathematics elective (select one of the following):		3-5
Any MATH (101 or higher)		
CS 109	Introduction to Probability for Computer Scientists	
PHYSICS 112	Mathematical Methods for Physics	
STATS 116	Theory of Probability	
EE 261	The Fourier Transform and Its Applications	
Intermediate Sequence		
PHYSICS 105	Intermediate Physics Laboratory I: Analog Electronics	4
PHYSICS 107	Intermediate Physics Laboratory II: Experimental Techniques and Data Analysis	4
PHYSICS 112	Mathematical Methods for Physics (recommended) [1]	
PHYSICS 113	Computational Physics (recommended) [2]	
PHYSICS 120	Intermediate Electricity and Magnetism I	4
PHYSICS 121	Intermediate Electricity and Magnetism II	4
Advanced Sequence		
Advanced Project Lab (select one of the following): [5]		4
PHYSICS 100	Introduction to Observational Astrophysics	
PHYSICS 108	Advanced Physics Laboratory: Project	
PHYSICS 113	Computational Physics	
PHYSICS 110	Advanced Mechanics	4
PHYSICS 130	Quantum Mechanics I	4
PHYSICS 131	Quantum Mechanics II	4
PHYSICS 134	Advanced Topics in Quantum Mechanics (recommended) [2]	
PHYSICS 170	Thermodynamics, Kinetic Theory, and Statistical Mechanics I	4
PHYSICS 171	Thermodynamics, Kinetic Theory, and Statistical Mechanics II	4

1 Those wishing to pursue theoretical physics in graduate school may wish to take a collection of courses in the Department of Mathematics rather than or in addition to PHYSICS 112 Mathematical Methods for Physics.

2 These courses are not required. PHYSICS 113 Computational Physics is recommended for students planning to work in technical fields; it may also be used to satisfy the Advanced Project Lab requirement.. Both PHYSICS 113 Computational Physics and PHYSICS 134 Advanced Topics in Quantum Mechanics are recommended for students who intend to complete a Ph.D. in Physics.

3 MATH 51H, 52H and/or 53H, offered prior to 2016-17, may be substituted for the MATH 50 and/or 60CM series. CME courses may not be substituted.

[4] In years when MATH 173 Theory of Partial Differential Equations is not offered, MATH 220 Partial Differential Equations of Applied Mathematics is a recommended alternative.

[5] Starting with Spring Quarter 2018, any one of PHYSICS 100 Introduction to Observational Astrophysics, PHYSICS 108 Advanced Physics Laboratory: Project, or PHYSICS 113 Computational Physics can be used to satisfy the Advanced Project Lab course requirement. Students may not count PHYSICS 100 or PHYSICS 113 for this requirement if taken in 2017 or earlier.

To prepare for physics research and careers in science and technology, Physics majors are advised to take at least one course in statistics (e.g., STATS 116) and at least one programming course (e.g., CS 106A, B or X). PHYSICS 113 and 91SI offer opportunities to develop proficiency in applying numerical techniques and computational skills. Physics majors who wish to prepare for more data-intensive work could consider a minor in Computer Science.

Concentrations 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 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 receive a certificate of completion of a concentration.

To choose a concentration complete at least four courses from one of the 5 subject areas in the list below, or three courses plus a senior thesis. No more than one of the courses can be taken for Credit/No Credit (CR/NC). All other courses must be completed with a grade of 'C-' or better. 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. Applied Physics (Hari Manoharan (manoharan@stanford.edu)**)**

		Units
Solid State		
PHYSICS 172	Solid State Physics	3
APPPHYS 270	Magnetism and Long Range Order in Solids	3
MATSCI 195	Waves and Diffraction in Solids	3-4
Lasers		
EE 236A	Modern Optics	3
EE 236C	Lasers	3
Lab Methods		
APPPHYS 207	Laboratory Electronics	4

B. Astrophysics (Bruce Macintosh (bmacintosh@stanford.edu)**)**

		Units
AA 279A	Space Mechanics	3
EE 238	Introduction to Fourier Optics	3
PHYSICS 100	Introduction to Observational Astrophysics	4
PHYSICS 160	Introduction to Stellar and Galactic Astrophysics	3
PHYSICS 161	Introduction to Cosmology and Extragalactic Astrophysics	3
Select one of the following:		3
PHYSICS 211	Continuum Mechanics	
PHYSICS 262	General Relativity	

PHYSICS 160 and PHYSICS 161 are jointly taught to undergraduates and graduate students (PHYSICS 260 and PHYSICS 261 are for graduate students). Undergraduates must register for 160/161 not 260/261.

C. Biophysics and Medical Physics (Surya Ganguli (SXDWC@SLAC.Stanford.Edu)**)**

		Units
BIOC 202	Biochemistry Bootcamp	1
BIO 141	Biostatistics	5
BIOE 221	Physics and Engineering of Radionuclide-based Medical Imaging	3
BIOE 222	Physics and Engineering Principles of Multi-modality Molecular Imaging of Living Subjects	4
BIOE 279	Computational Biology: Structure and Organization of Biomolecules and Cells	3

It is recommended that Physics majors interested in pursuing a career in biophysics consider a minor in Biology.

D. Geophysics (Dustin Schroeder (Dustin.M.Schroeder@stanford.edu)**)**
The Concentration in Geophysics consists of GEOPHYS 110 Introduction to the Foundations of Contemporary Geophysics plus three courses in Geophysics of at least 3 units numbered 120 and above. Geophysics 196, 197, 198 may be used for one of the courses if a thesis is completed.

E. Theoretical Physics (Andrei Linde (alinde@stanford.edu)**)**

		Units
PHYSICS 152	Introduction to Particle Physics I	3
PHYSICS 160	Introduction to Stellar and Galactic Astrophysics	3
PHYSICS 161	Introduction to Cosmology and Extragalactic Astrophysics	3
PHYSICS 262	General Relativity	3
PHYSICS 330	Quantum Field Theory I	3
PHYSICS 331	Quantum Field Theory II	3
PHYSICS 332	Quantum Field Theory III	3
PHYSICS 351	Standard Model of Particle Physics	3
PHYSICS 450	Advanced Theoretical Physics I: String Theory with Applications to Cosmology and Black Hole Physics (Not offered 2018-2019)	3
PHYSICS 451	Advanced Theoretical Physics II: Quantum Information Theory, Complexity, Gravity and Black Holes	3
PHYSICS 470	Topics in Modern Condensed Matter Theory I: Topological States of Matter	3
PHYSICS 471	Topics in Modern Condensed Matter Theory II: Physics of the Quantum Hall Regime (Not offered 2018-2019)	3

Notes to students taking this concentration:

1. Students should discuss the choice of courses with members of the Institute for Theoretical Physics and/or their major adviser.
2. Students may attend PHYSICS 330 Quantum Field Theory I after taking PHYSICS 130 Quantum Mechanics I, PHYSICS 131 Quantum Mechanics II and PHYSICS 134 Advanced Topics in Quantum Mechanics.
3. Students who took PHYSICS 362 or PHYSICS 364 in previous years may also count these towards fulfillment of this requirement.

Senior Thesis

The department offers Physics majors the opportunity to complete a senior thesis. These are the guidelines:

1. Students must submit a Senior Thesis Application form once they identify a physics project, either theoretical or experimental, in consultation with individual faculty members. Proposal forms are available from the undergraduate coordinator and must be submitted by the week prior to the Thanksgiving break of the academic year in which the student plans to graduate.
2. Credit for the project is assigned by the adviser within the framework of PHYSICS 205 Senior Thesis Research. A minimum of 3 units of PHYSICS 205 Senior Thesis Research must be completed for a letter grade during the senior year. Work completed in the senior thesis program may not be used as a substitute for regular required courses for the Physics major.
3. A written report and a presentation of the work at its completion are required for the senior thesis. By mid-May, the senior thesis candidate is required to present the project at the department's Senior Thesis Presentation Program. This event is publicized and open to the general public. The expectation is that the student's adviser, second reader, and all other senior thesis candidates attend.

Honors Program

Physics majors are granted a Bachelor of Science in Physics with Honors if they satisfy these three requirements beyond the general Physics major requirements:

1. The student files for entry into the honors program by completing an Honors Program Application (available from the undergraduate coordinator) by the same deadline as the Senior Thesis Application. Eligibility is confirmed by the department.
2. The student completes a senior thesis by meeting the deadlines and requirements described above.
3. The student completes course work with an overall GPA of 3.30 or higher, and a GPA of 3.50 or higher in courses required for the Physics major.

Minor in Physics

The Physics minor allows the student to select a concentration in Physics or Astronomy. The Astronomy concentration has a technical and non-technical option.

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 except as noted in the following paragraph.

Students who take the PHYSICS 20, 40, or 60 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 40 level by enrollment at another accredited university, or through advanced placement credits, may count credits towards PHYSICS 21, PHYSICS 23, and PHYSICS 24, or PHYSICS 41/PHYSICS 42 and PHYSICS 43/PHYSICS 44.

PHYSICS 25/PHYSICS 26, or PHYSICS 45 /PHYSICS 46 for a minor in Physics or the technical minor concentration in Astronomy, must be taken at Stanford even if similar material has been covered elsewhere.

The minor declaration deadline is three quarters before graduation, typically the beginning of Autumn Quarter if the student is graduating at the end of Spring Quarter.

Concentration in Physics

An undergraduate minor in Physics requires a minimum of 25 units with the following course work:

		Units
Select one of the following Series:		16-19
Series A (19 units)		
PHYSICS 41 & PHYSICS 42	Mechanics and Classical Mechanics Laboratory	
PHYSICS 43 & PHYSICS 44	Electricity and Magnetism and Electricity and Magnetism Lab [1]	
PHYSICS 45 & PHYSICS 46	Light and Heat and Light and Heat Laboratory	
PHYSICS 70	Foundations of Modern Physics	
Series B (16 units)		
PHYSICS 61 & PHYSICS 62	Mechanics and Special Relativity and Mechanics Laboratory	
PHYSICS 65 & PHYSICS 67	Quantum and Thermal Physics and Introduction to Laboratory Physics	
PHYSICS 63 & PHYSICS 64	Electricity, Magnetism, and Waves and Electricity, Magnetism and Waves Laboratory	
At least three PHYSICS courses numbered 100 or above from the following courses: PHYSICS 100, 105, 107, 108, 110, 111, 112, 113, 120, 121, 130, 131, 134, 152, 160, 161, 166, 170, 171, 172, 182, 199, 211, 212, 216, 220, 230, 231, 262.		9-12
Total Units		25-31

[1] PHYSICS 67 Introduction to Laboratory Physics may be substituted for PHYSICS 44 Electricity and Magnetism Lab.

Minor in Physics with Concentration in Astronomy

Students wishing to pursue advanced work in astrophysical sciences should major in Physics (p. 3) 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 Physics minor concentration programs.

Students who take the 20, 40, or 60 series at Stanford in support of their major may count those units towards the minor.

An undergraduate Physics minor with a concentration in Astronomy requires the following courses:

Non-Technical

For students whose majors do not require the PHYSICS 40 or 60 series:

		Units
PHYSICS 21	Mechanics, Fluids, and Heat	4
PHYSICS 23	Electricity, Magnetism, and Optics	4
PHYSICS 25 & PHYSICS 26	Modern Physics and Modern Physics Laboratory	5
PHYSICS 50	Astronomy Laboratory and Observational Astronomy	3-4
or PHYSICS 100	Introduction to Observational Astrophysics	
Select two of the following:		6
PHYSICS 15	Stars and Planets in a Habitable Universe	
PHYSICS 16	The Origin and Development of the Cosmos	
PHYSICS 17	Black Holes and Extreme Astrophysics	

Technical

For students whose majors require the PHYSICS 40 or 60 series:

		Units
Select one of the following Series:		14-17
Series A		
PHYSICS 41	Mechanics	
PHYSICS 43	Electricity and Magnetism	
PHYSICS 45 & PHYSICS 46	Light and Heat and Light and Heat Laboratory	
PHYSICS 70	Foundations of Modern Physics	
Series B		
PHYSICS 61	Mechanics and Special Relativity	
PHYSICS 63	Electricity, Magnetism, and Waves	
PHYSICS 65	Quantum and Thermal Physics	
PHYSICS 67	Introduction to Laboratory Physics	
And take the following three courses:		
PHYSICS 100	Introduction to Observational Astrophysics	4
PHYSICS 160	Introduction to Stellar and Galactic Astrophysics	3
PHYSICS 161	Introduction to Cosmology and Extragalactic Astrophysics	3
Total Units		24-27

Students are also encouraged to take the electricity and magnetism/optics lab of the appropriate PHYSICS series , PHYSICS 24 , PHYSICS 44 or PHYSICS 64 for 1 additional unit.

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 (http://exploredegrees.stanford.edu/graduatedegrees)" section of this bulletin, include completion of 45 units of unduplicated course work after the bachelor's degree. Course taken to fulfill the degree requirements below must be taken for a letter grade. Among the department requirements are a grade point average (GPA) of at least 3.0 (B) for the following required courses (or their equivalents):

		Units
PHYSICS 212	Statistical Mechanics	3
PHYSICS 220	Classical Electrodynamics	3
Plus one of the following courses:		
PHYSICS 230	Graduate Quantum Mechanics I	3
PHYSICS 231	Graduate Quantum Mechanics II	3
PHYSICS 234	Advanced Topics in Quantum Mechanics	3
PHYSICS 330	Quantum Field Theory I	3
PHYSICS 331	Quantum Field Theory II	3
PHYSICS 332	Quantum Field Theory III	3
Plus two 3 unit graduate level courses in Physics or Applied Physics.		6

Up to 6 of these required units may be waived on petition if a thesis is submitted.

Doctor of Philosophy in Physics

The University's basic requirements for the Ph.D. are discussed in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees)" 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 course from each of two subject areas outside the student's primary area of research (among biophysics, condensed matter, quantum optics and atomic physics, astrophysics and gravitation, and nuclear and particle physics). For this requirement students must choose from courses numbered above PHYSICS 234, excluding 290 and 294. All courses taken to fulfill the Physics Ph.D. degree requirements must be taken for a letter grade, except for PHYSICS 290 and PHYSICS 294 which are only offered for Satisfactory/No Credit.

The requirements in the following list may be fulfilled by passing the course at Stanford or passing an equivalent course elsewhere:

		Units
PHYSICS 212	Statistical Mechanics	3
PHYSICS 220	Classical Electrodynamics	3
PHYSICS 290	Research Activities at Stanford	1
PHYSICS 294	Teaching of Physics Seminar	1
Plus one of the following courses:		
PHYSICS 230	Graduate Quantum Mechanics I	3
PHYSICS 231	Graduate Quantum Mechanics II	3
PHYSICS 234	Advanced Topics in Quantum Mechanics	3
PHYSICS 330	Quantum Field Theory I	3
PHYSICS 331	Quantum Field Theory II	3
PHYSICS 332	Quantum Field Theory III	3

A grade point average (GPA) of at least 3.0 (B) is required for courses taken toward the degree.

All Ph.D. candidates must have math proficiency equivalent to the following Stanford MATH courses:

		Units
MATH 106	Functions of a Complex Variable	3
MATH 113	Linear Algebra and Matrix Theory	3
MATH 116	Complex Analysis	3
PHYSICS 111	Partial Differential Equations of Mathematical Physics	4
PHYSICS 112	Mathematical Methods for Physics	4

Prior to making an application for candidacy, each student is required to pass a comprehensive oral qualifying examination. 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 are 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 (http://exploredegrees.stanford.edu/schoolofhumanitiesandsciences/astronomy)" section of this bulletin.

Ph.D. Minor in Physics

Doctoral students seeking a minor in Physics must take at least six courses from the following list: 210, 211, 212, 216, 220, 230, 231, and 234 among the 20 required units. Courses must be taken for a letter grade. All prospective minors must obtain approval of their Physics course program from the Physics Graduate Study Committee at least one year before conferral of the Ph.D.

Graduate Advising Expectations

The Department of Physics is committed to providing academic advising in support of graduate student scholarly and professional development. When most effective, this advising relationship entails collaborative and sustained engagement by both the adviser and the advisee. As a best practice, advising expectations should be periodically discussed and reviewed to ensure mutual understanding. Both the adviser and the advisee are expected to maintain professionalism and integrity.

Faculty advisers guide students in key areas such as selecting courses, designing and conducting research, developing of teaching pedagogy, navigating policies and degree requirements, and exploring academic opportunities and professional pathways.

Graduate students are active contributors to the advising relationship, proactively seeking academic and professional guidance and taking responsibility for informing themselves of policies and degree requirements for their graduate program.

For a statement of University policy on graduate advising, see the "Graduate Advising (http://exploredegrees.stanford.edu/graduatedegrees/#advisingandcredentialstext)" section of this bulletin.

Emeriti: (Professors) Alexander L. Fetter, William A. Little, Douglas D. Osheroff, David M. Ritson, H. Alan Schwettman, Robert V. Wagoner, John Dirk Walecka, Stanley G. Wojcicki, Mason R. Yearian; (Professors, Research) John A. Lipa, Todd I. Smith, John P. Turneaure; (Professor, Courtesy) Peter A. Sturrock (Applied Physics), Richard Taylor (SLAC National Accelerator Laboratory)

Chair: Shamit Kachru

Associate Chair: Peter F. Michelson

Professors: Tom Abel, Steven Allen, Roger Blandford, Phil Bucksbaum, Patricia Burchat, Blas Cabrera, Steven Chu, Sarah Church, Persis Drell, Savas G. Dimopoulos, Sebastian Doniach, David Goldhaber-Gordon, Giorgio Gratta, Patrick Hayden, Kent Irwin, Shamit Kachru, Steven Kahn, Renata E. Kallosh, Aharon Kapitulnik, Mark Kasevich, Steven A. Kivelson, Robert B. Laughlin, Andrei D. Linde, Bruce Macintosh, Kathryn Moler, Peter F. Michelson, Vahe Petrosian, Roger W. Romani, Zhi-Xun Shen, Stephen Shenker, Eva Silverstein, Leonard Susskind, Carl Wieman, Shoucheng Zhang

Associate Professors: Peter Graham, Sean Hartnoll, Chao-Lin Kuo, Benjamin Lev, Hari Manoharan, Xiao-liang Qi, Srinivas Raghu, Leonardo Senatore, Douglas Stanford (untenured), Risa Wechsler

Assistant Professors: Benjamin Feldman, Jason Hogan, Monika Schleier-Smith, Douglas Stanford, Lauren Tompkins

Professors (Research): Leo Hollberg, Phillip H. Scherrer

Courtesy Professors: Daniel Akerib, Rhiju Das, Craig Levin, Stephen Quake, Thomas Shutt, Richard N. Zare

Lecturers: Ryan Hazelton, Chaya Nanavati, Rick Pam, Timothy Wiser

Adjunct Professor: Ralph DeVoe, Steve Yellin