PHYSICS

Courses offered by the Department of Physics are listed under the subject code PHYSICS on the Stanford Bulletin’s ExploreCourses website.

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://exploredoegrees.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:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYSICS 15</td>
<td>Stars and Planets in a Habitable Universe</td>
<td>3</td>
</tr>
<tr>
<td>PHYSICS 16</td>
<td>The Origin and Development of the Cosmos</td>
<td>3</td>
</tr>
<tr>
<td>PHYSICS 17</td>
<td>Black Holes and Extreme Astrophysics</td>
<td>3</td>
</tr>
<tr>
<td>PHYSICS 19</td>
<td>How Things Work: An Introduction to Physics (not offered 2019-20)</td>
<td>3</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYSICS 21</td>
<td>Mechanics, Fluids, and Heat</td>
<td>4</td>
</tr>
<tr>
<td>PHYSICS 22</td>
<td>Mechanics, Fluids, and Heat Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>PHYSICS 23</td>
<td>Electricity, Magnetism, and Optics</td>
<td>4</td>
</tr>
<tr>
<td>PHYSICS 24</td>
<td>Electricity, Magnetism, and Optics Laboratory</td>
<td>1</td>
</tr>
<tr>
<td>PHYSICS 25</td>
<td>Modern Physics</td>
<td>4</td>
</tr>
<tr>
<td>PHYSICS 26</td>
<td>Modern Physics Laboratory</td>
<td>1</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Digit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>intermediate and advanced undergraduate courses</td>
</tr>
<tr>
<td>200</td>
<td>first-year graduate courses</td>
</tr>
</tbody>
</table>
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/academics/undergraduate-students/placement-diagnostic). 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-diagnostic. Also see the Physics Placement Diagnostic web site (https://physics.stanford.edu/sites/g/files/sbybj6226/f/revised_4_year_plans_2019.pdf) illustrating how to complete the Physics major.

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.

Required Math Courses (21-24 units)

- MATH 51 Linear Algebra, Multivariable Calculus, and Modern Applications
- MATH 61CM Modern Mathematics: Continuous Methods
- MATH 52 Integral Calculus of Several Variables
- MATH 62CM Modern Mathematics: Continuous Methods
- MATH 53 Ordinary Differential Equations with Linear Algebra
- MATH 63CM Modern Mathematics: Continuous Methods
- PHYSICS 111 Partial Differential Equations of Mathematical Physics
- PHYSICS 131P Partial Differential Equations
- PHYSICS 173 Theory of Partial Differential Equations

Plus one advanced mathematics elective (select one of the following):

- 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
- PHYSICS 107 Intermediate Physics Laboratory II: Experimental Techniques and Data Analysis
- PHYSICS 112 Mathematical Methods for Physics (recommended)
- PHYSICS 113 Computational Physics (recommended)
- PHYSICS 120 Intermediate Electricity and Magnetism I
- PHYSICS 121 Intermediate Electricity and Magnetism II

Advanced Sequence

Advanced Project Lab (select one of the following):

- PHYSICS 100 Introduction to Observational Astrophysics
- PHYSICS 108 Advanced Physics Laboratory: Project
- PHYSICS 113 Computational Physics
- PHYSICS 110 Advanced Mechanics
- PHYSICS 130 Quantum Mechanics I
- PHYSICS 131 Quantum Mechanics II
- PHYSICS 134 Advanced Topics in Quantum Mechanics (recommended)
- PHYSICS 170 Thermodynamics, Kinetic Theory, and Statistical Mechanics I
- PHYSICS 171 Thermodynamics, Kinetic Theory, and Statistical Mechanics II

- PHYSICS 111 Computational Physics
- PHYSICS 121 Intermediate Electricity and Magnetism II

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.

6 Although not generally recommended, students with sufficient lab preparation who do not take any of the introductory lab courses (42, 44, 46, 62, 64, 67) may substitute a second advanced lab course (100, 108, 113) for all three required introductory labs. Note that in this case, taking any of the introductory labs does not in any way reduce the requirement of taking a second advanced lab. In general, only a second advanced lab, not any other courses, may substitute for the intro labs. A student must apply to take advantage of this option using the usual course substitution form.

Graduate classes in quantum mechanics (PHYSICS 230, PHYSICS 231), statistical mechanics (PHYSICS 212), and E&M (PHYSICS 220) may not be substituted for any of the related Physics major requirements (PHYSICS 130, PHYSICS 131, PHYSICS 170, PHYSICS 171, PHYSICS 120, PHYSICS 121). Undergraduate courses are specifically designed to give a solid introduction to the subject including all the different pieces that are important for a foundation. Graduate classes are not faster, more advanced versions of the same topics, but may leave out certain topics entirely. In addition, the midterms and final exams in the undergraduate courses facilitate synthesis of material that is important for physics students. So it is important and valuable to take the undergraduate classes.

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, CS 106B or CS 106X). In addition, PHYSICS 113 and PHYSICS 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. (PHYSICS 91SI is a student-initiated course and may not be counted toward the completion of degree requirements.)

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

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYSICS 172</td>
<td>Solid State Physics</td>
<td>3</td>
</tr>
<tr>
<td>MATSCI 195</td>
<td>Waves and Diffraction in Solids</td>
<td>4</td>
</tr>
<tr>
<td>EE 236A</td>
<td>Modern Optics</td>
<td>3</td>
</tr>
<tr>
<td>EE 236C</td>
<td>Lasers</td>
<td>3</td>
</tr>
<tr>
<td>APPPHYS 207</td>
<td>Laboratory Electronics</td>
<td>4</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYSICS 100</td>
<td>Introduction to Observational Astrophysics</td>
<td>4</td>
</tr>
<tr>
<td>PHYSICS 160</td>
<td>Introduction to Stellar and Galactic</td>
<td>3</td>
</tr>
<tr>
<td>Astrophysics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHYSICS 161</td>
<td>Introduction to Cosmology and Extragalactic Astrophysics</td>
<td>3</td>
</tr>
</tbody>
</table>

Select one of the following:

- AA 279A: Space Mechanics - 3 units
- EE 238: Introduction to Fourier Optics - 3 units
- PHYSICS 262: General Relativity - 3 units

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

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIO 141</td>
<td>Biostatistics</td>
<td>5</td>
</tr>
<tr>
<td>BIOE 221</td>
<td>Physics and Engineering of Radionuclide-</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>based Medical Imaging</td>
<td></td>
</tr>
<tr>
<td>BIOE 222</td>
<td>Physics and Engineering Principles of</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Multi-modality Molecular Imaging of Living</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Subjects</td>
<td></td>
</tr>
<tr>
<td>BIOE 279</td>
<td>Computational Biology: Structure and</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Organization of Biomolecules and Cells</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYSICS 160</td>
<td>Introduction to Stellar and Galactic</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Astrophysics</td>
<td></td>
</tr>
<tr>
<td>PHYSICS 161</td>
<td>Introduction to Cosmology and Extragalactic Astrophysics</td>
<td>3</td>
</tr>
<tr>
<td>PHYSICS 262</td>
<td>General Relativity</td>
<td>3</td>
</tr>
<tr>
<td>PHYSICS 330</td>
<td>Quantum Field Theory I</td>
<td>3</td>
</tr>
<tr>
<td>PHYSICS 331</td>
<td>Quantum Field Theory II</td>
<td>3</td>
</tr>
</tbody>
</table>
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:

Select one of the following Series:

<table>
<thead>
<tr>
<th>Series A (19 units)</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYSICS 41 Mechanics</td>
<td></td>
</tr>
<tr>
<td>&amp; PHYSICS 42 and Classical Mechanics Laboratory</td>
<td></td>
</tr>
<tr>
<td>PHYSICS 43 Electricity and Magnetism</td>
<td></td>
</tr>
<tr>
<td>&amp; PHYSICS 44 and Electricity and Magnetism Lab</td>
<td></td>
</tr>
<tr>
<td>PHYSICS 45 Light and Heat</td>
<td></td>
</tr>
<tr>
<td>&amp; PHYSICS 46 and Light and Heat Laboratory</td>
<td></td>
</tr>
<tr>
<td>PHYSICS 70 Foundations of Modern Physics</td>
<td></td>
</tr>
</tbody>
</table>

Series B (16 units)

<table>
<thead>
<tr>
<th>PHYSICS 61 Mechanics and Special Relativity</th>
<th>Mechanics Laboratory</th>
</tr>
</thead>
<tbody>
<tr>
<td>&amp; PHYSICS 62 and Mechanics Laboratory</td>
<td></td>
</tr>
<tr>
<td>PHYSICS 65 Quantum and Thermal Physics</td>
<td></td>
</tr>
<tr>
<td>&amp; PHYSICS 67 and Introduction to Laboratory Physics</td>
<td></td>
</tr>
<tr>
<td>PHYSICS 63 Electricity, Magnetism, and Waves</td>
<td></td>
</tr>
<tr>
<td>&amp; PHYSICS 64 Electricity, Magnetism and Waves Laboratory</td>
<td></td>
</tr>
</tbody>
</table>

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.

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:

<table>
<thead>
<tr>
<th>PHYSICS 21 Mechanics, Fluids, and Heat</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYSICS 23 Electricity, Magnetism, and Optics</td>
<td>Units</td>
</tr>
</tbody>
</table>
At least 3.0 (B) for the following required courses (or their equivalents):

Among the department requirements are a grade point average (GPA) of at least 3.0 for the following required courses (or their equivalents):

Select two of the following:

- **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

Total Units: 22-23

### 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** Light and Heat
- **PHYSICS 46** Light and Heat Laboratory
- **PHYSICS 70** Foundations of Modern Physics

And take the following three courses:

- **PHYSICS 100** Introduction to Observational Astronomy
- **PHYSICS 160** Introduction to Stellar and Galactic Astrophysics
- **PHYSICS 161** Introduction to Cosmology and Extragalactic Astrophysics

Total Units: 24-27

Students are also encouraged to take the electricity and magnetism/physics 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 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:

- **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

Total Units: 22-23

### 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.


Chair: Shamit Kachru

Director of Undergraduate Studies: Peter Graham

Director of Graduate Studies: Sean Hartnoll


Associate Professors: Peter Graham, Sean Hartnell, Benjamin Lev, Hari Manoharan, Srinivas Raghu, Monika Schleier-Smith, Leonardo Senatore, Douglas Stanford (untenured)

Assistant Professors: Benjamin Feldman, Jason Hogan, Vedika Khemani, 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: Julien Devin, Ryan Hazelton, Chaya Nanavati, Rick Pam

Adjunct Professor: Adam Brown, Ralph DeVoe, Steve Yellin