Physics

Physics students study the basic laws of mechanics, heat and thermodynamics, electricity and magnetism, optics, relativity, quantum mechanics, and elementary particles. Students also study applications of the basic theories to the description of bulk matter, including the mechanical, electric, magnetic, and thermal properties of solids, liquids, gases, and plasmas, and to the description of the structure of atoms and nuclei. In addition, students develop the laboratory skills and techniques of the experimental physicist, skills that can be applied in the experimental search for new knowledge or in applications relating to known theories.

A majority of physics graduates go to graduate school in physics, often earning the Ph.D. degree. These graduates take university or college faculty positions, or work on research in a variety of university, government, or industrial laboratories. Some students choose employment immediately after the bachelor’s degree. They use their many approved and free electives to supplement their science background with applied courses, such as engineering, to develop the skills needed for a position in a particular area.

Because of the fundamental role of physics in all natural sciences, students also use the physics major as an excellent preparation for graduate study in many other scientific areas, such as optical engineering, applied mathematics, computer science, biophysics, molecular biology, astrophysics, geology and geophysics, materials science and engineering, meteorology, or physical oceanography. Attractive engineering areas with a high science content include optical communications, aeronautical engineering, nuclear engineering, including both fission and fusion devices; electrical engineering, including instrumentation; electronics and solid-state devices, electrical discharges and other plasma-related areas; and mechanical engineering and mechanics, including fluids and continuum mechanics. The broad scientific background developed in the physics curriculum is also an excellent background for professional schools, such as law (particularly patent law), medicine, and optometry.

Lehigh offers three undergraduate degrees in physics and two undergraduate degrees in astronomy or astrophysics. The three physics degrees are the bachelor of arts with a major in physics and the bachelor of science in physics in the College of Arts and Sciences and, and the bachelor of engineering physics in the College of Engineering and Applied Science. The B.A. with a major in astronomy and the B.S. in astrophysics are in the College of Arts and Sciences and are described in the Astronomy and Astrophysics section of this catalog.

In addition, there are several five-year, dual-degree programs involving physics: The Arts-Engineering program (see the Arts-Engineering section of this catalog), the combination of the bachelor of science program in the College of Arts and Sciences with electrical engineering (described below), and the combination of electrical engineering and engineering physics (see the Electrical Engineering and Engineering Physics section of this catalog).

The bachelor of science curriculum in the College of Arts and Sciences requires somewhat more physics and mathematics than the bachelor of arts major, while the latter provides more free electives and fewer hours for graduation. By making good use of the electives in these programs, students can pursue graduate work in physics or physical aspects of other science or engineering disciplines, or technical careers requiring a basic knowledge of physics. The bachelor of arts curriculum is particularly useful for those planning careers in areas where some knowledge of physics is needed or useful, but is not the main subject, such as science writing, secondary school teaching, patent law, or medicine. The bachelor of science in engineering physics curriculum in the College of Engineering and Applied Science requires an engineering concentration in either solid state electronics or optical sciences, in addition to regular physics and mathematics courses. This four-year program prepares students to do engineering work in an overlap area between physics and engineering. This may involve engineering in a forefront area in which it is desirable to have more physics knowledge than that typically provided in an engineering program. It may be a field of experimental physics which either relies heavily on forefront engineering or in which the nature of the problem dictates that scientists and engineers will accomplish more working together rather than separately.

Requirements and recommended course sequences are described below for programs in the College of Arts and Sciences and in the P. C. Rossin College of Engineering and Applied Science. Note that no more than 6 credits of military science may be applied toward any degree program.

**Professors.** Ivan Biaggio, PhD (ETH Zurich); Gary G. DeLeo, PhD (University of Connecticut); Volkmar R. Dierolf, PhD (University of Utah); John P. Huennekens, PhD (University of Colorado Boulder); Alvin S. Kanofsky, PhD (University of Pennsylvania); Yong W. Kim, PhD (University of Michigan Ann Arbor); H. Daniel Ou-Yang, PhD (University of California Los Angeles); Jeffrey M. Rickman, PhD (Carnegie Mellon University); Michael J. Stavola, PhD (University of Rochester); Jean Toulouse, PhD (Columbia University)

**Associate Professors.** Jerome C. Licini, PhD (Massachusetts Institute of Technology); Mary Virginia McSwain, PhD (Georgia State University)

**Assistant Professors.** Sera Cremonini, PhD (Brown University); Aurelia Honerkamp Smith, PhD (University of Washington); Joshua A. Pepper, PhD (Ohio State University); Rosi Jan Reed, PhD (University of California Davis); Ariel T. Sommer, PhD (Massachusetts Institute of Technology)

**Professor Of Practice.** Paola M Cereghetti Biaggio, PhD (Swiss Federal Institute of Technology)

**Emeriti.** Garold J Borse, PhD (University of Virginia); W. Beall Fowler, PhD (University of Rochester); James D. Gunton, PhD (Stanford University); Albert Peet Hickman, PhD (Rice University); Arnold H. Kritz, PhD (Yale University); George Eadon McCluskey, Jr., PhD (University of Pennsylvania); Sheldon H. Radin, PhD (Yale University); Russell A. Shaffer, PhD (Johns Hopkins University)

**COLLEGE OF ARTS AND SCIENCES**

**B.A. with Major in Physics Program Requirements**

<table>
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<th>Credits</th>
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<tr>
<td>PHY 010</td>
<td>General Physics I</td>
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</tr>
<tr>
<td>or PHY 011</td>
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<td></td>
</tr>
<tr>
<td>PHY 013</td>
<td>General Physics II</td>
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<td>or PHY 021</td>
<td>Introductory Physics II</td>
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</tr>
<tr>
<td>PHY 012</td>
<td>Introductory Physics Laboratory I</td>
<td>1</td>
</tr>
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<td>PHY 022</td>
<td>Introductory Physics Laboratory II</td>
<td>1</td>
</tr>
<tr>
<td>PHY 031</td>
<td>Introduction to Quantum Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>MATH 021</td>
<td>Calculus I</td>
<td>4</td>
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<td>MATH 022</td>
<td>Calculus II</td>
<td>4</td>
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<tr>
<td>MATH 023</td>
<td>Calculus III</td>
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<tr>
<td>MATH 205</td>
<td>Linear Methods</td>
<td>3</td>
</tr>
<tr>
<td>CHM 030</td>
<td>Introduction to Chemical Principles</td>
<td>4</td>
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Select at least one of the following:

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<tbody>
<tr>
<td>PHY 190</td>
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<tr>
<td>PHY 262</td>
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Select at least 6 of the following:

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<td>Modern Astrophysics</td>
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<td>PHY 215</td>
<td>Classical Mechanics I</td>
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<td>High-Energy Astrophysics</td>
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<td>Thermal Physics</td>
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<td>PHY 342</td>
<td>Relativity and Cosmology</td>
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<td>PHY 348</td>
<td>Plasma Physics</td>
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<td>PHY 352</td>
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<td>PHY 355</td>
<td>Nonlinear Optics</td>
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<tr>
<td>PHY 362</td>
<td>Atomic and Molecular Structure</td>
<td></td>
</tr>
<tr>
<td>PHY 363</td>
<td>Physics of Solids</td>
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</table>
A total of 120 credits are required for the BA in Physics

B.S. in Physics Program Requirements

Mathematics Courses

<table>
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<td>MATH 021</td>
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<td>MATH 022</td>
<td>Calculus II</td>
<td>4</td>
</tr>
<tr>
<td>MATH 023</td>
<td>Calculus III</td>
<td>4</td>
</tr>
<tr>
<td>MATH 205</td>
<td>Linear Methods</td>
<td>3</td>
</tr>
<tr>
<td>MATH 208</td>
<td>Complex Variables</td>
<td>3-4</td>
</tr>
<tr>
<td>or MATH 320</td>
<td>Ordinary Differential Equations</td>
<td></td>
</tr>
<tr>
<td>or MATH 322</td>
<td>Methods of Applied Analysis I</td>
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Basic Science Courses

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<td>PHY 011</td>
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<tr>
<td>or PHY 010</td>
<td>General Physics I</td>
<td></td>
</tr>
<tr>
<td>PHY 021</td>
<td>Introductory Physics II</td>
<td>4</td>
</tr>
<tr>
<td>or PHY 023</td>
<td>Introductory Physics II with Relativity</td>
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<tr>
<td>PHY 012</td>
<td>Introductory Physics Laboratory I</td>
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</tr>
<tr>
<td>PHY 022</td>
<td>Introductory Physics Laboratory II</td>
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</tr>
<tr>
<td>PHY 031</td>
<td>Introduction to Quantum Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>CHM 030</td>
<td>Introduction to Chemical Principles</td>
<td>4</td>
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</tbody>
</table>

Laboratory and Computing Courses

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<tr>
<td>CSE 002</td>
<td>Fundamentals of Programming</td>
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<tr>
<td>PHY 220</td>
<td>Advanced Physics Laboratory I</td>
<td>3</td>
</tr>
<tr>
<td>PHY 221</td>
<td>Advanced Physics Laboratory II</td>
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</table>

*Or an equivalent course in scientific computing.

Intermediate and Advanced Courses

<table>
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<th>Credits</th>
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<td>PHY 212</td>
<td>Electricity and Magnetism I</td>
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<td>PHY 213</td>
<td>Electricity and Magnetism II</td>
<td>3</td>
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<tr>
<td>PHY 215</td>
<td>Classical Mechanics I</td>
<td>4</td>
</tr>
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<td>PHY 340</td>
<td>Thermal Physics</td>
<td>3</td>
</tr>
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<td>PHY 362</td>
<td>Atomic and Molecular Structure</td>
<td>3</td>
</tr>
<tr>
<td>PHY 364</td>
<td>Nuclear and Elementary Particle Physics</td>
<td>3</td>
</tr>
<tr>
<td>PHY 369</td>
<td>Quantum Mechanics I</td>
<td>3</td>
</tr>
</tbody>
</table>

Approved Elective Courses

Select two courses from among...

<table>
<thead>
<tr>
<th>Course</th>
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<tr>
<td>PHY 363</td>
<td>Physics of Solids</td>
<td>3</td>
</tr>
<tr>
<td>PHY 352</td>
<td>Modern Optics</td>
<td>3</td>
</tr>
<tr>
<td>or PHY 355</td>
<td>Nonlinear Optics</td>
<td></td>
</tr>
<tr>
<td>PHY 348</td>
<td>Plasma Physics</td>
<td>3</td>
</tr>
<tr>
<td>or PHY 365</td>
<td>Physics Of Fluids</td>
<td></td>
</tr>
<tr>
<td>PHY 380</td>
<td>Introduction to Computational Physics</td>
<td>3</td>
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</tbody>
</table>

... plus three additional courses in appropriate technical areas in consultation with the adviser. Students planning graduate work in Physics are advised to include PHY 273 (Research) among their electives.

Total Credits: 90-92

A total of 123 credits are required for the BS in Physics

RECOMMENDED SEQUENCE OF COURSES

The recommended sequence of courses for physics degree programs are indicated below. General electives are not indicated, but they should be selected in consultation with the adviser so that educational goals and total credit hour requirements are satisfied.
### MATH 023  4  PHY 190  3
### ECO 001  4  MATH 205  3
### ECE 081  4  MATH 208  3
###  ECE 123  3

#### Third Year

<table>
<thead>
<tr>
<th>Fall</th>
<th>Credits</th>
<th>Spring</th>
<th>Credits</th>
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<tr>
<td>PHY 212</td>
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<td>PHY 213</td>
<td>3</td>
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<tr>
<td>ECE 033</td>
<td>4</td>
<td>PHY 262</td>
<td>2</td>
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<td>ECE 108</td>
<td>4</td>
<td>PHY 215</td>
<td>4</td>
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<tr>
<td>MATH 322</td>
<td>3</td>
<td>ECE 126</td>
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<td>HSS</td>
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<td>HSS</td>
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<tr>
<td>Elective</td>
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#### Fourth Year

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<th>Spring</th>
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<td>PHY 340 or ME 104</td>
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<td>PHY 355</td>
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<td>PHY 352</td>
<td>3</td>
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<tr>
<td>OE –Elec</td>
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<td>OE –Elec</td>
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<tr>
<td>Electives</td>
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<td>HSS</td>
<td>3</td>
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</table>

#### Total Credits: 131

(1) The 18 credit hours of OE (Optical Engineering) electives must include ECE 257 or ECE 258 or PHY 273. Must include at least two of ECE 347, ECE 348, ECE 371, ECE 372. Other advanced physics or engineering courses may be included among the OE electives with the approval of the student’s advisor.

### COMBINED B.S.(PHYSICS)/B.S.(ELECTRICAL ENGINEERING)

The combined arts/engineering programs resulting in bachelors degrees in both physics and electrical engineering may be arranged so that either of the two degrees is completed within the first four years. The suggested curricula are:

#### with a concentration in Optical Sciences

##### First Year

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<tr>
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<td>ENGL 001</td>
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<td>ENGL 002</td>
<td>3</td>
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<td>CHM 030</td>
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<td>MATH 021</td>
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<td>MATH 022</td>
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<tr>
<td>ENGR 005</td>
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<td>ENGR 010</td>
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<td>HSS</td>
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##### Second Year

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<th>Spring</th>
<th>Credits</th>
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<tbody>
<tr>
<td>PHY 021 &amp; PHY 022</td>
<td>5</td>
<td>PHY 031</td>
<td>3</td>
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<td>MATH 023</td>
<td>4</td>
<td>PHY 190</td>
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<td>ECO 001</td>
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<td>MATH 205</td>
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<td>ECE 081</td>
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<td>MATH 208</td>
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<td>HSS</td>
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##### Third Year

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<th>Credits</th>
<th>Spring</th>
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<tr>
<td>PHY 212</td>
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<td>PHY 213</td>
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<tr>
<td>PHY 362</td>
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<td>PHY 262</td>
<td>2</td>
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<tr>
<td>ECE 108</td>
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<td>PHY 215</td>
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<td>MATH 322</td>
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##### Fourth Year

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<tr>
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##### Fifth Year

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<tr>
<td>ECE 257</td>
<td>3</td>
<td>ECE 258</td>
<td>2</td>
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</tbody>
</table>
Physics approved electives

Select three of the following:

- PHY 363 Physics of Solids
- PHY 369 Quantum Mechanics I
- PHY 352 Modern Optics
- or PHY 355 Nonlinear Optics
- PHY 348 Plasma Physics
- or PHY 365 Physics Of Fluids
- PHY 380 Introduction to Computational Physics

Total Credits: 162

Students must satisfy both the HSS requirements of the College of Engineering and Applied Science and the distribution requirements, including the junior writing intensive requirement, of the College of Arts and Sciences. Courses appropriate for both may be counted in both categories.

Approved electives are subject to the approval of the student’s advisor. Students planning graduate work in physics are advised to include PHY 273 and PHY 369 among their electives.

ASTRONOMY/ASTrophysics DEGREE PROGRAMS

(See the Astronomy (http://catalog.lehigh.edu/coursesprogramsandcurricula/artsandsciences/astronomyandastrophysics) section in this catalog.)

RESEARCH OPPORTUNITIES

A majority of physics, astronomy, and engineering physics majors take advantage of opportunities to participate in research under the direction of a faculty member. Research areas available to undergraduates are the same as those available to graduate students; they are described below under the heading For Graduate Students. Undergraduate student research is arranged informally as early as the sophomore (or, occasionally, freshman) year at the initiation of the student or formally as a senior research project. In addition, a number of students receive financial support to do research during the summer between their junior and senior years, either as Physics Department Summer Research Participants or as Sherman Fairchild Scholars.

The use of electives

The electives available in each of the physics and astronomy curricula provide the student with an opportunity to develop special interests and to prepare for graduate work in various allied areas. In particular, the many available upper-level physics, mathematics, and engineering courses can be used by students in consultation with their faculty advisors to structure programs with special emphases in a variety of areas such as optical communications, solid-state electronics, or biophysics.

DEPARTMENTAL HONORS

Students may earn departmental honors by satisfying the following requirements:

- Grade point average of at least 3.50 in physics courses.
- Complete 6 credits of PHY 273 (research), or summer REU project, submit a written report, and give an oral presentation open to faculty and students.
- Complete three courses from the list:
  - Select one of the following:
    - PHY 332 High-Energy Astrophysics
    - PHY 342 Relativity and Cosmology
    - PHY 348 Plasma Physics
    - PHY 363 Physics of Solids
    - PHY 352 Modern Optics
    - or PHY 355 Nonlinear Optics
    - PHY 369 Quantum Mechanics I
    - PHY 380 Introduction to Computational Physics
- Any 400 level Physics course

For students majoring in astronomy or astrophysics, see the Astronomy and Astrophysics section of this catalog.

FIVE-YEAR COMBINED BACHELOR/MASTER’S PROGRAMS

Five-Year programs that lead to successive bachelor and master’s degrees are available. These programs satisfy all of the requirements of one of the five bachelor’s degrees in physics (B.A., B.S., B.S.E.P.) and astronomy/astrophysics (B.A., B.S.), plus the requirements of the
THE MINOR PROGRAM
The minor in physics consists of 15 credits of physics courses, excluding PHY 005 and ASTR 007. No more than one physics course required in a student’s major program may be included in the minor program. The minor program must be designed in consultation with the physics department chair.

FOR GRADUATE STUDENTS
The department of physics has concentrated its research activities within several fields of physics, with the result that a number of projects are available in each area. Current departmental research activities include the following:

Condensed matter physics. Areas of interest include the optical and electronic properties of defects in semiconductors and insulators, quantum phenomena in semiconductor devices, collective dynamics of disordered solids, structural phase transitions in ferroelectrics and superconducting crystals, theory of quantum charge transport in nanotubes and single molecule systems, physics of nano devices.

Atomic and molecular physics. Research topics include atomic and molecular spectroscopy and collision processes. Recent work has addressed velocity-changing collisions, diffusion, energy-pooling collisions, charge exchange, fine structure mixing, light-induced drift and radiation trapping.

Cosmology and string theory: This research area examines the fundamental structure of spacetime and the quantum nature of gravity. Research directions include a wide range of topics in quantum field theory and string theory, with applications to strongly coupled gauge theories, gravity and theoretical cosmology.

High-energy physics: The department provides both theoretical and experimental research opportunities in the field of high-energy physics. Experimental work involves the examination of the quark gluon plasma (QGP) created in heavy-ion collisions by using particle jets and heavy flavor quarks as probes of the medium. These studies make use of the Solenoidal Tracker (STAR) detector at the Relativistic Heavy Ion Collider (RHIC), and other accelerator experiments. Theoretical studies address fundamental aspects and phenomenological applications of string theory, gravitational descriptions of quantum field theory, and gauge/string dualities.

Nonlinear optics and photonics. Research topics include nonlinear light-matter interaction that enable the control of light with light, four-wave mixing, phase conjugation, resonant Brillouin scattering, ferroelectric domain patterning for quasi phase matching, waveguides, photonic crystals, holey and other specialty fibers, and the application of photonics to biological systems.

Plasma physics. Computational studies of magnetically confined toroidal plasmas address anomalous thermal and particle transport, large scale instabilities, and radiofrequency heating. Laboratory studies address collisional and collisionless phenomena of supercritical laser-produced plasmas.

Statistical physics. Investigation is underway of nonequilibrium fluctuations in gases, chaotic transitions and 1/f dynamics, light-scattering spectroscopy, colloidal suspensions, the nonlinear dynamics of granular particles, and pattern formation in nonequilibrium dissipative systems, including the kinetics of phase transitions and spatiotemporal chaos.

Soft condensed matter and biological physics. Current research topics include both the experimental and theoretical studies of complex fluids including biological polymers, colloids, and biological cells and tissues. Laser tweezers, Raman scattering, photoluminescence and advanced 3-D optical imaging techniques are integrated for investigating the structures and dynamical properties of these systems. Theoretical studies focus on the kinetics of phase transitions, including the crystallization of globular and membrane proteins and also the modeling of interactions of proteins and nanotubes.

Complex fluids. Polymers in aqueous solutions, colloidal suspensions, and surfactant solutions are investigated using techniques such as “laser tweezers,” video-enhanced microscopy, and laser light scattering. Areas of interest include the structures of polymers at liquid-solid interfaces and microstructure of confined macromolecules. Recent work addresses systems of biological significance.

Computational physics. Several of the above areas involve the use of state-of-the-art computers to address large-scale computational problems. Areas of interest include atom-atom collisions, simulations of tokamak plasmas, the statistical behavior of ensembles of many particles, the calculation of electronic wave functions for molecules and solids, and the multi-scale modeling of nano-bio systems. Candidates for advanced degrees normally will have completed, before beginning their graduate studies, the requirements for a bachelor’s degree with a major in physics, including advanced mathematics beyond differential and integral calculus. Students lacking the equivalent of this preparation will make up deficiencies in addition to taking the specified work for the degree sought.

At least eight semester hours of general college physics using calculus are required for admission to all 200- and 300-level courses. Additional prerequisites for individual courses are noted in the course descriptions. Admission to 400-level courses generally is predicated on satisfactory completion of corresponding courses in the 200- and 300-level groups or their equivalent.

FACILITIES FOR RESEARCH
Research facilities are housed in the Sherman Fairchild Center for the Physical Sciences, containing Lewis Laboratory, the Sherman Fairchild Laboratory for Solid State Studies, and a large connecting research wing. Well-equipped laboratory facilities are available for experimental investigations in research areas at the frontiers of physics. Instruments used for experimental studies include a wide variety of laser systems ranging from femtosecond and picosecond pulsed lasers to stabilized single-mode cw Ti-sapphire and dye lasers. There is also a Fourier-transform spectrometer, cryogenic equipment that achieves temperatures as low as 0.05K and magnetic fields up to 9 Tesla, a facility for luminescence microscopy, and a laser-tweezers system for studies of complex fluids. The Fairchild Laboratory also contains a processing laboratory where advanced Si devices can be fabricated and studied. All laboratories are well furnished with electronic instrumentation for data acquisition and analysis.

Several professors are members of the interdisciplinary Center for Optical Technologies that offers a wide range of state-of-the-art facilities including a fiber drawing tower, waveguide and fiber characterization labs, and a new epitaxy facility for the growth of III-V semiconductor structures and devices. Extensive up-to-date computer facilities are available on campus and in the department. All computing resources can be accessed directly from graduate student and faculty offices through a high speed backbone. Researchers have access to the national Research Internet (Internet 2) via a 155 Mbps gateway.

Courses
PHY 005 Concepts In Physics 4 Credits
Fundamental discoveries and concepts of physics and their relevance to current issues and modern technology. For students not intending to major in science or engineering. Lectures, demonstrations, group activities, and laboratories using modern instrumentation and computers. This is a non-calculus course; no previous background in physics is assumed. Three class meetings and one laboratory period per week.

Attribute/Distribution: NS
PHY 009 Introductory Physics I Completion 1-2 Credits
For students who have Advanced Placement or transfer credit for 2 or 3 credits of PHY 11. The student will be scheduled for the appropriate part of PHY 11 to complete the missing material. The subject matter and credit hours will be determined by the Physics Department for each student. Students with AP Physics C credit for mechanics will take the thermodynamics and kinetic theory part of PHY 11 for one credit. Consent of department required.
Prerequisites: MATH 021 or MATH 031 or MATH 051 or MATH 076 or MATH 075
Can be taken Concurrently: MATH 021, MATH 031, MATH 051, MATH 076, MATH 075
Attribute/Distribution: NS

PHY 010 General Physics I 4 Credits
Statics, dynamics, conservation laws, thermodynamics, kinetic theory of gases, fluids. Primarily for architecture, biological science, earth and environmental science students.
Prerequisites: MATH 021 or MATH 031 or MATH 051 or MATH 076 or MATH 075
Can be taken Concurrently: MATH 021, MATH 031, MATH 051, MATH 076, MATH 075
Attribute/Distribution: NS

PHY 011 Introductory Physics I 4 Credits
Kinematics, frames of reference, laws of motion in Newtonian theory and in special relativity, conservation laws, as applied to the mechanics of mass points; temperature, heat and the laws of thermodynamics; kinetic theory of gases. Two lectures and two recitations per week.
Prerequisites: MATH 021 or MATH 031 or MATH 051 or MATH 076 or MATH 075
Can be taken Concurrently: MATH 021, MATH 031, MATH 051, MATH 076, MATH 075
Attribute/Distribution: NS

PHY 012 Introductory Physics Laboratory I 1 Credit
A laboratory course taken concurrently with PHY 10 or 11. Experiments in mechanics, heat, and DC electrical circuits. One three-hour laboratory period per week.
Prerequisites: PHY 010 or PHY 011
Can be taken Concurrently: PHY 010, PHY 011
Attribute/Distribution: NS

PHY 013 General Physics II 3 Credits
A continuation of PHY 10, primarily for biological science and earth and environmental science students. Electrostatics, electromagnetism, light, sound, atomic physics, nuclear physics, and radioactivity.
Prerequisites: (PHY 010 or PHY 011) and (MATH 021 or MATH 031 or MATH 051)
Can be taken Concurrently: MATH 021, MATH 031, MATH 051
Attribute/Distribution: NS

PHY 019 Introductory Physics II Completion 1-2 Credits
For students who have Advanced Placement or transfer credit for 2 or 3 credits of PHY 21. The student will be scheduled for the appropriate part of PHY 21 to complete the missing material. The subject matter and credit hours will be determined by the Physics Department for each student. Students with AP Physics C credit for electricity and magnetism will take the optics and modern physics part of PHY 21 for one credit. Consent of instructor required.
Prerequisites: (PHY 010 or PHY 011) and (MATH 022 or MATH 032 or MATH 052)
Attribute/Distribution: NS

PHY 021 Introductory Physics II 4 Credits
A continuation of PHY 11. Electrostatics and magnetostatics; DC circuits; Maxwell’s equations; waves; physical and geometrical optics; introduction to modern physics. Two lectures and two recitations per week. May not be taken by students who have previously completed PHY 023.
Prerequisites: (PHY 010 or PHY 011) and (MATH 022 or MATH 032 or MATH 052)
Attribute/Distribution: NS

PHY 022 Introductory Physics Laboratory II 1 Credit
A laboratory course to be taken concurrently with PHY 13 or 21. One three-hour laboratory period per week.
Prerequisites: (PHY 012) and (PHY 021 or PHY 013 or PHY 023)
Can be taken Concurrently: PHY 021, PHY 013, PHY 023
Attribute/Distribution: NS

PHY 023 Introductory Physics II with Relativity 4 Credits
A version of PHY 021 for students interested in majoring in physics or astrophysics, or students with a strong interest in related fields. It is well-suited for students with PHY 011 AP credit, or with PHY 021 AP credit who wish to replace that course with a more sophisticated version. The theory of electricity and magnetism is developed from a modern point of view, emphasizing the unity of electric and magnetic fields in the context of special relativity.
Prerequisites: (PHY 010 or PHY 011) and (MATH 022 or MATH 032 or MATH 052)
Attribute/Distribution: NS

PHY 031 Introduction to Quantum Mechanics 3 Credits
Experimental basis and historical development of quantum mechanics; the Schroedinger equation; one-dimensional problems; angular momentum and the hydrogen atom; many-electron systems; spectra; selected applications. Three lectures per week.
Prerequisites: (PHY 013 or PHY 021 or PHY 023) and MATH 205
Can be taken Concurrently: MATH 205
Attribute/Distribution: NS

PHY 035 Dynamics 3 Credits
Conservation laws, Newton’s laws of motion, angular momentum and the hydrogen atom; many-electron systems; rotation of coordinate systems; rigid body motions; topics from Lagrange’s and Hamilton’s formulations of mechanics; continuum mechanics.
Prerequisites: (PHY 021 or PHY 013 or PHY 023) and MATH 205
Can be taken Concurrently: MATH 205
Attribute/Distribution: NS

PHY 090 Electricity and Magnetism I 3 Credits
Electrostatics, magnetostatics, and electromagnetic induction.
Prerequisites: (PHY 021 or PHY 013 or PHY 023) and MATH 205
Can be taken Concurrently: MATH 205
Attribute/Distribution: NS

PHY 091 Electricity and Magnetism II 3 Credits
Maxwell’s equations, Poynting’s theorem, potentials, the wave equation, waves in vacuum and in materials, transmission and reflection at boundaries, guided waves, dispersion, electromagnetic field of moving charges, radiation, Lorentz invariance and other symmetries of Maxwell’s equations.
Prerequisites: PHY 021
Attribute/Distribution: NS

PHY 092 Classical Mechanics I 4 Credits
Kinematics and dynamics of point masses with various force laws; conservation laws; systems of particles; rotating coordinate systems; rigid body motions; topics from Lagrange’s and Hamilton’s formulations of mechanics; continuum mechanics.
Prerequisites: (PHY 021 or PHY 013 or PHY 023) and MATH 205
Can be taken Concurrently: MATH 205
Attribute/Distribution: NS

PHY 093 Classical Mechanics II 4 Credits
A continuation of PHY 11. Electrodynamics and magnetostatics; DC circuits; Maxwell’s equations; waves; physical and geometrical optics; introduction to modern physics. Two lectures and two recitations per week. May not be taken by students who have previously completed PHY 023.
Prerequisites: (PHY 010 or PHY 011) and (MATH 022 or MATH 032 or MATH 052)
Attribute/Distribution: NS
PHY 220 Advanced Physics Laboratory I 3 Credits
In a lab/lecture format, students learn basic elements needed for experimental, observational and computational work in physics, astrophysics and other technical areas. This course and its continuation as PHY 221 include topics such as electronics, optics, vacuum systems, data acquisition and analysis, curve fitting, scientific computing, interfacing of computers to experiments, and modern machining. These methods will be utilized in the examination of various physical systems: e.g., atomic and molecular spectroscopy, astronomical observations, condensed-matter phenomena, and others.
Prerequisites: (PHY 021 or PHY 023) and PHY 022 and CSE 002
Attribute/Distribution: NS

PHY 221 Advanced Physics Laboratory II 2 Credits
This is a continuation of PHY 220.
Prerequisites: (PHY 021 or PHY 023) and PHY 022 and PHY 220
Attribute/Distribution: NS

PHY 262 Advanced Physics Laboratory 2 Credits
Laboratory practice, including machine shop, vacuum systems, and computer interfacing. Experiment selected from geometrical optics, interference and diffraction, spectroscopy, lasers, fiber optics, and quantum phenomena.
Prerequisites: (PHY 013 or PHY 021 or PHY 023) and PHY 022
Attribute/Distribution: NS

PHY 272 Special Topics In Physics 1-4 Credits
Selected topics not sufficiently covered in other courses.
Repeat Status: Course may be repeated.

PHY 273 Research 2-3 Credits
Participation in current research projects being carried out within the department.
Repeat Status: Course may be repeated.
Attribute/Distribution: NS

PHY 281 Basic Physics I 3 Credits
A course designed especially for secondary-school teachers in the master teacher program. Presupposing a background of two semesters of college mathematics through differential and integral calculus and of two semesters of college physics, the principles of physics are presented with emphasis on their fundamental nature rather than on their applications. Open only to secondary-school teachers and those planning to undertake teaching of secondary-school physics.
Attribute/Distribution: NS

PHY 282 Basic Physics II 3 Credits
Continuation of PHY 281.
Prerequisites: PHY 010 or PHY 011 or PHY 281
Attribute/Distribution: NS

PHY 300 Apprentice Teaching 1-4 Credits

PHY 321 (BIOE 321) Biomolecular & Cellular Mechanics 3 Credits
Mechanics and physics of the components of the cell, ranging in length scale from fundamental biomolecules to the entire cell. The course covers the mechanics of proteins and other biopolymers in 1D, 2D, and 3D structures, cell membrane structure and dynamics, and the mechanics of the whole cell.
Prerequisites: MATH 205 and MATH 231 and PHY 022 and (PHY 013 or PHY 021 or PHY 023)
Attribute/Distribution: NS

PHY 331 (BIOE 331) Integrated Bioelectronics/Biophotonics Laboratory 2 Credits
Experiments in design and analysis of bioelectronics circuits, micropatterning of biological cells, micromanipulation of biological cells using electric fields, analysis of pacemakers, instrumentation and computer interfaces, ultrasound, optic, laser tweezers and advanced imaging and optical microscopy techniques for biological applications.
Prerequisites: (PHY 013 or PHY 021 or PHY 023) and PHY 022 and ECE 121 and ECE 123 and (PHY 190 or ECE 081)
Can be taken Concurrently: ECE 121, ECE 123
Attribute/Distribution: NS

PHY 332 (ASTR 332) High-Energy Astrophysics 3 Credits
Observation and theory of X-ray and gamma-ray sources, quasars, pulsars, radio galaxies, neutron stars, black holes. Results from ultraviolet, X-ray and gamma-ray satellites. Generally offered in the spring of odd-numbered years.
Prerequisites: (PHY 021 or PHY 023) and (MATH 023 or MATH 033)
Can be taken Concurrently: MATH 023, MATH 033
Attribute/Distribution: NS

PHY 340 Thermal Physics 3 Credits
Basic principles of thermodynamics, kinetic theory, and statistical mechanics, with emphasis on applications to classical and quantum mechanical physical systems.
Prerequisites: (PHY 013 or PHY 021 or PHY 023) and (MATH 023 or MATH 032 or MATH 052)
Attribute/Distribution: NS

PHY 342 (ASTR 342) Relativity and Cosmology 3 Credits
Special and general relativity. Schwarzschild and Kerr black holes. Super massive stars. Relativistic theories of the origin and evolution of the universe. Generally offered in the spring of even-numbered years.
Prerequisites: (PHY 021 or PHY 023) and (MATH 023 or MATH 033)
Can be taken Concurrently: MATH 023, MATH 033
Attribute/Distribution: NS

PHY 348 Plasma Physics 3 Credits
Single particle behavior in electric and magnetic fields, plasmas as fluids, waves in plasmas, transport properties, kinetic theory of plasmas, controlled thermonuclear fusion devices. Must have senior standing or consent of the department chair.
Prerequisites: (PHY 021 or PHY 023) and MATH 205
Attribute/Distribution: NS

PHY 352 Modern Optics 3 Credits
Paraxial optics, wave and vectorial theory of light, coherence and interference, diffraction, crystal optics, and lasers.
Prerequisites: MATH 205 and (PHY 212 or ECE 202)
Attribute/Distribution: NS

PHY 355 Nonlinear Optics 3 Credits
This course will introduce the fundamental principles of nonlinear optics. Topics include nonlinear interaction of optical radiation with matter, multi-photon interactions, electro-optics, self and cross phase modulation, and the nonlinear optical susceptibilities that describe all these effects in the mainframe of electromagnetic theory.
Prerequisites: PHY 031 and (PHY 213 or ECE 203)
Can be taken Concurrently: PHY 213, ECE 203
Attribute/Distribution: NS

PHY 362 Atomic and Molecular Structure 3 Credits
Review of quantum mechanical treatment of one-electron atoms, electron spin and fine structure, multi-electron atoms, Pauli principle, Zeeman and Stark effects, hyperfine structure, structure and spectra of simple molecules.
Prerequisites: PHY 031 or CHM 341
Attribute/Distribution: NS

PHY 363 Physics of Solids 3 Credits
Introduction to the theory of solids with particular reference to the physics of metals and semiconductors.
Prerequisites: (PHY 031 or MAT 316 or CHM 341) and PHY 340
Can be taken Concurrently: PHY 340
Attribute/Distribution: NS

PHY 364 Nuclear and Elementary Particle Physics 3 Credits
Models, properties, and classification of nuclei and elementary particles; nuclear and elementary particle reactions and decays; radiation and particle detectors; accelerators; applications.
Prerequisites: PHY 031 and MATH 205
Attribute/Distribution: NS

PHY 365 Physics Of Fluids 3 Credits
Concepts of fluid dynamics; continuum and molecular approaches; waves, shocks and nozzle flows; nature of turbulence; experimental methods of study.
Prerequisites: (PHY 212 or ECE 202) and (PHY 340 or ME 104)
Can be taken Concurrently: PHY 212, ECE 202, PHY 340, ME 104
Attribute/Distribution: NS
PHY 366 Introduction to String Theory 3 Credits
Introduction to string theory for upper-level undergraduates and beginning graduate students. Building on Einstein’s theory of general relativity and quantum theory, this course covers the fundamentals of string theory and the latest developments. Advanced topics such as D-branes, non-perturbative dualities and holography will also be covered. The course content is appropriate to students who have a working knowledge of quantum mechanics and special relativity, and have had some exposure to general relativity. Instructor permission required in lieu of Phy 362/369.
Prerequisites: PHY 031 and PHY 215 and (PHY 362 or PHY 369)
Can be taken Concurrently: PHY 369
Attribute/Distribution: NS

PHY 369 Quantum Mechanics I 3 Credits
Prerequisites: PHY 031 and MATH 205 and PHY 215
Can be taken Concurrently: PHY 215
Attribute/Distribution: NS

PHY 372 Special Topics In Physics 1-3 Credits
Selected topics not sufficiently covered in other courses.
Repeat Status: Course may be repeated.
Attribute/Distribution: NS

PHY 380 Introduction to Computational Physics 3 Credits
Numerical solution of physics and engineering problems using computational techniques. Topics include linear and nonlinear equations, interpolation, eigenvalues, ordinary differential equations, partial differential equations, statistical analysis of data, Monte Carlo, and molecular dynamics methods.
Prerequisites: MATH 205
Can be taken Concurrently: MATH 205
Attribute/Distribution: NS

PHY 389 Honors Project 1-8 Credits
Course may be repeated.

PHY 411 Survey Nuclear Particles and Elementary Particle Physics 3 Credits
Intended for non-specialists. Fundamentals and modern advanced topics in nuclear and elementary particle physics. Topics include: nuclear force, structure of nuclei, nuclear models and reactions, scattering, elementary particle classification, SU(3), quarks, gluons, quark flavor and color, leptons, gauge theories, GUT, the big bang.
Prerequisites: PHY 369

PHY 420 Mechanics 3 Credits
Includes the variational methods of classical mechanics, methods of Hamilton and Lagrange, canonical transformations, Hamilton-Jacobi Theory.

PHY 421 Electricity & Magnetism I 3 Credits
Electrostatics, magnetostatics, Maxwell’s equations, dynamics of charged particles, multipole fields.

PHY 422 Electricity & Magnetism II 3 Credits
Electrodynamics, electromagnetic radiation, physical optics, electrodynamics in anisotropic media. Special theory of relativity.
Prerequisites: PHY 421

PHY 424 Quantum Mechanics II 3 Credits
General principles of quantum theory; approximation methods; spectra; symmetry laws; theory of scattering.
Prerequisites: PHY 369

PHY 425 Quantum Mechanics III 3 Credits
Prerequisites: PHY 424

PHY 428 Methods of Mathematical Physics I 3 Credits
Analytical and numerical methods of solving the ordinary and partial differential equations that occur in physics and engineering. Includes treatments of complex variables, special functions, product solutions and integral transforms.
Prerequisites: PHY 352
PHY 490 Thesis 1-6 Credits

PHY 491 Research 3 Credits
Research problems in experimental or theoretical physics.

PHY 492 Research 3 Credits
Continuation of PHY 491.
Repeat Status: Course may be repeated.

PHY 499 Dissertation 1-15 Credits
Repeat Status: Course may be repeated.