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 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); Volkmar Dierolf, PhD (University of Utah); Yong W. Kim, PhD (University of Michigan); 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); Dimitrios Vavylonis, PhD (Columbia University)

Associate Professors. Sera Cremonini, PhD (Brown University); Jerome Licini, PhD (Massachusetts Institute of Technology); Ginny McSwain, PhD (Georgia State University); Joshua A. Pepper, PhD (Ohio State University); Rosi Reed, PhD (University of California, Davis)

Assistant Professors. Chinedu Ekuma, PhD (Louisiana State University); Aurelia Honerkamp Smith, PhD (University of Washington); Anders Knospe, PhD (Yale University); Bitan Roy, PhD (Simon Fraser Univ); Ariel Sommer, PhD (Massachusetts Institute of Technology); Timm Wrase, PhD (University of Texas at Austin)

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

Emeriti. Gary DeLeo, PhD (University of Connecticut); Beall Fowler, PhD (University of Rochester); Albert Peet Hickman, PhD (Rice University); John P. Huennekens, PhD (University of Colorado Boulder); George Eadon McCluskey, Jr., PhD (University of Pennsylvania); Shelden H. Radin, PhD (Yale University); Russell A. Shaffer, PhD (Johns Hopkins University); George D. Watkins, PhD (Harvard University)

COLLEGE OF ARTS AND SCIENCES

B.A. with Major in Physics Program Requirements

PHY 010	General Physics I	4
or PHY 011	Introductory Physics I	
PHY 013	General Physics II	3-4
or PHY 021	Introductory Physics II	
PHY 012	Introductory Physics Laboratory I	1
PHY 022	Introductory Physics Laboratory II	1
PHY 031	Introduction to Modern Physics	3
PHY 220	Advanced Physics Laboratory I	3
MATH 021	Calculus I	4
MATH 022	Calculus II	4
MATH 023	Calculus III	4
MATH 205	Linear Methods	3
CHM 030	Introduction to Chemical Principles	4
Select at least 6 of the following:		18
PHY 212	Electricity and Magnetism I	
PHY 213	Electricity and Magnetism II	
ASTR 301	Introduction to Stellar Astrophysics	
PHY 215	Classical Mechanics I	
PHY 332	High-Energy Astrophysics	
PHY 340	Thermal Physics	
PHY 342	General Relativity	
PHY 348	Plasma Physics	
PHY 352	Modern Optics	
PHY 355	Nonlinear Optics	
PHY 362	Quantum Mechanics I	
PHY 363	Physics of Solids	

PHY 364	Nuclear and Elementary Particle Physics	
PHY 365	Physics Of Fluids	
PHY 369	Quantum Mechanics II	
PHY 380	Introduction to Computational Physics	
Total Credits		**52-53**

A total of 120 credits are required for the BA in Physics

B.S. in Physics Program Requirements

Mathematics Courses		
MATH 021	Calculus I	4
MATH 022	Calculus II	4
MATH 023	Calculus III	4
MATH 205	Linear Methods	3
MATH 208	Complex Variables	3-4
or MATH 320	Ordinary Differential Equations	
or MATH 322	Methods of Applied Analysis I	
Basic Science Courses		
PHY 011	Introductory Physics I	4
or PHY 010	General Physics I	
PHY 021	Introductory Physics II	4
PHY 012	Introductory Physics Laboratory I	1
PHY 022	Introductory Physics Laboratory II	1
PHY 031	Introduction to Modern Physics	3
CHM 030	Introduction to Chemical Principles	4
Laboratory and Computing Courses		
CSE 003	Introduction to Programming, Part A	2
or CSE 007	Introduction to Programming	
PHY 220	Advanced Physics Laboratory I	3
PHY 221	Advanced Physics Laboratory II	2
*Or an equivalent course in scientific computing.		
Intermediate and Advanced Courses		
PHY 212	Electricity and Magnetism I	3
PHY 213	Electricity and Magnetism II	3
PHY 215	Classical Mechanics I	4
PHY 340	Thermal Physics	3
PHY 362	Quantum Mechanics I	3
PHY 364	Nuclear and Elementary Particle Physics	3
PHY 369	Quantum Mechanics II	3
Elective Courses		**15**
Select five Physics or Astronomy courses numbered higher than 100. Up to two courses in appropriate technical areas offered in other departments may be substituted, when selected with advisor approval. Students planning graduate work in physics are encouraged to include PHY 273 (Research) among their electives.		
Total Credits		**79-80**

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 advisor so that educational goals and total credit hour requirements are satisfied.

B.A. with a Major in Physics, College of Arts & Sciences

First Year			
Fall	CR	Spring	CR
ENGL 001	3	ENGL 002	3
PHY 010 or 011	4	CHM 030	4
PHY 012	1	MATH 022	4
MATH 021	4	Dist. Req.	4
Col. Sem.	3-4		
	15-16		**15**
Second Year			
Fall	CR	Spring	CR
PHY 013 or 021	3-4	PHY 031	3
PHY 022	1	MATH 205	3
MATH 023	4	Elective	6-7
Dist. Req.	8	Dist. Req.	4
	16-17		**16-17**

Total Credits: 62-65

B.S. in Physics, College of Arts & Sciences

First Year			
Fall	CR	Spring	CR
ENGL 001	3	ENGL 002	3
PHY 011 or 010	4	CHM 030	4
PHY 012	1	MATH 022	4
MATH 021	4	Col. Sem. or Dist. Req.	3-4
Col. Sem. or Dist. Req.	3-4		
	15-16		**14-15**
Second Year			
Fall	CR	Spring	CR
PHY 021	4	PHY 031	3
PHY 022	1	CSE 003 or 007	2-4
MATH 023	4	MATH 205	3
Dist. Req.	3-4	Dist. Req.	3-4
Elective or Dist. Req.	3-4	Elective or Dist. Req.	3-4
	15-17		**14-18**

Total Credits: 58-66

*
Or an equivalent course in scientific computing.

P.C. ROSSIN COLLEGE OF ENGINEERING & APPLIED SCIENCES

Both concentrations require 131 credit hours. The tables below indicate both course requirements and recommended enrollment sequences.

Bachelor of Engineering Physics
with a concentration in Solid State Electronics

First Year			
Fall	Credits	Spring	Credits
ENGL 001	3	ENGL 002	3
PHY 011 & PHY 012	5	CHM 030	4
MATH 021	4	MATH 022	4
ENGR 005	2	ENGR 010	2
		HSS	3
	14		**16**
Second Year			
Fall	Credits	Spring	Credits
PHY 021 & PHY 022	5	PHY 031	3
MATH 023	4	MATH 205	3
ECO 001	4	MATH 208	3
ECE 081	4	ECE 123	3
		HSS	4
	17		**16**

Third Year

Fall	Credits	Spring	Credits
PHY 212	3	PHY 213	3
PHY 220	3	PHY 221	2
ECE 033	4	PHY 215	4
ECE 108	4	ECE 126	3
MATH 322	3	HSS	3
		Elective	3
	17		**18**

Fourth Year

Fall	Credits	Spring	Credits
PHY 340 or ME 104	3	HSS	3
PHY 363	3	SSE -Elec (1)	8
PHY 362	3	Electives	6
SSE –Elec	3		
Elective	4		
	16		**17**

Total Credits: 131

(1) The 11 credit hours of SSE (Solid State Engineering) electives must include ECE 257 or ECE 258 or PHY 273.
Other advanced physics or engineering courses may be included among the SSE electives with the approval of the student's advisor.

with a concentration in Optical Sciences

First Year

Fall	Credits	Spring	Credits
ENGL 001	3	ENGL 002	3
PHY 011 & PHY 012	5	CHM 030	4
MATH 021	4	MATH 022	4
ENGR 005	2	ENGR 010	2
		HSS	3
	14		**16**

Second Year

Fall	Credits	Spring	Credits
PHY 021 & PHY 022	5	PHY 031	3
MATH 023	4	MATH 205	3
ECO 001	4	MATH 208	3
ECE 081	4	HSS	4
		OE- Elec (1)	3
	17		**16**

Third Year

Fall	Credits	Spring	Credits
PHY 212	3	PHY 213	3
PHY 220	3	PHY 221	2
PHY 362	3	PHY 215	4
ECE 108	4	OE –Elec	3
MATH 322	3	HSS	3
		Elective	3
	16		**18**

Fourth Year

Fall	Credits	Spring	Credits
PHY 340 or ME 104	3	PHY 355	3
PHY 352	3	Electives	4
OE –Elec	6	OE –Elec	6
Electives	6	HSS	3
	18		**16**

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:

Physics-Elec. Engr (Physics first)

First Year

Fall	CR	Spring	CR
ENGL 001	3	ENGL 002	3
PHY 011 & PHY 012	5	CHM 030	4
MATH 021	4	MATH 022	4
ENGR 005	2	ENGR 010	2
		Col. Sem.	3
	14		**16**

Second Year

Fall	CR	Spring	CR
PHY 021 & PHY 022	5	PHY 031	3
MATH 023	4	ECO 001	4
ECE 033	4	MATH 205	3
ECE 081	4	MATH 208	3
		HSS/Dist. Req.	4
	17		**17**

Third Year

Fall	CR	Spring	CR
PHY 212	3	PHY 213	3
PHY 362	3	PHY 221	2
ECE 108	4	PHY 364	3
ECE 182	1	PHY 215	4
MATH 322	3	ECE 121	2
Jr. Writing	3	ECE 123	3
	17		**17**

Fourth Year

Fall	CR	Spring	CR
PHY 340	3	ECE 126	3
PHY Appr. Elective	6	ECE 138	2
HSS/Dist. Req.	6	ECE 125	3
Elective	3	PHY Appr. Elective	6
		HSS/Dist. Req.	3
	18		**17**

Fifth Year

Fall	CR	Spring	CR
ECE 257	3	ECE 258	2
MATH 231	3	ECE Appr Elective	9
ECE 136	3	Elective	3
ECE Appr Elective	3		

Elective	3		
	15		**14**

Total Credits: 162

Elec. Engr-Physics (Electrical Engineering First)

First Year			
Fall	**CR**	**Spring**	**CR**
ENGL 001	3	ENGL 002	3
PHY 011 & PHY 012	5	CHM 030	4
MATH 021	4	MATH 022	4
ENGR 005	2	ENGR 010	2
		HSS/Dist. Req.	4
	14		**17**
Second Year			
Fall	**CR**	**Spring**	**CR**
PHY 021 & PHY 022	5	PHY 031	3
MATH 023	4	ECE 121	2
ECE 033	4	MATH 205	3
ECE 081	4	ECE 123	3
		HSS/Dist. Req.	6
	17		**17**
Third Year			
Fall	**CR**	**Spring**	**CR**
PHY 212	3	PHY 213	3
ECE 108	4	ECE 126	3
ECE 182	1	ECE 138	2
MATH 208	3	ECE 125	3
MATH 231	3	ECO 001	4
Jr. Writing	3		
	17		**15**
Fourth Year			
Fall	**CR**	**Spring**	**CR**
PHY 362	3	PHY 364	3
ECE 136	3	PHY 215	4
ECE 257	3	ECE 258	2
ECE Appr. Elective	6	ECE Appr. Elective	6
		HSS/Dist. Req.	3
	15		**18**
Fifth Year			
Fall	**CR**	**Spring**	**CR**
PHY 340	3	PHY 221	2
MATH 322	3	PHY Appr Elective	3
PHY Appr Elective	6	Electives	12
Electives	3		
	15		**17**

Total Credits: 162

Physics approved electives

Select three of the following:		9
PHY 363	Physics of Solids	
PHY 369	Quantum Mechanics II	
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		**9**

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:		3
PHY 332	High-Energy Astrophysics	
PHY 342	General Relativity	
PHY 348	Plasma Physics	3
PHY 363	Physics of Solids	3
PHY 352	Modern Optics	3
or PHY 355	Nonlinear Optics	
PHY 369	Quantum Mechanics II	3
PHY 380	Introduction to Computational Physics	3
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 M.S. in physics in the final year. Depending upon the undergraduate degree received, one summer in residence may be required.

Interested students should contact the associate chair of physics no later than the spring semester of their junior year for further detail.

THE MINOR PROGRAM

The minor in physics requires 15 credits of Physics and Astronomy courses. It must consist of the physics introductory sequence, plus 9 credits of physics courses at or above the 100 level. No more than one course required in a student's major program can be counted towards the number of credits for the physics minor. To account for this and to ensure a coherent intellectual theme, the program for an individual student is designed in consultation with and approved by the physics department chair. For the purpose of this minor, the physics introductory sequence consists of PHY 10 or PHY 11, PHY 13 or PHY 21, PHY 12, PHY 22, and PHY 31, or equivalent courses. Examples of course sequences for the minor program can be found on the Physics Department WebSite.

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:

Astronomy and Astrophysics. Current research involves theoretical and observational studies of stars and planets. Particular areas of interest in stellar astrophysics are young open clusters, binary stars, X-ray binaries, the formation of disks in Be stars, and stellar pulsations. Research on planets involves the discovery and characterization of exoplanets orbiting bright stars and the search for extraterrestrial life.

Atomic, Molecular, and Optical Physics. Current research investigates the physics of quantum many-body systems through studies of ultracold atomic gases. Topics include superfluidity, spin and heat transport, and thermodynamics of strongly interacting Fermi gases. Experiments employ laser cooling and optical trapping to produce quantum degenerate atomic gases, and tailored optical potentials, radiofrequency spectroscopy and other techniques to perform measurements. Research also includes thermalization and condensation of photons in dye media confined within a narrow optical cavity.

Biophysics. Researchers in the physics department employ experimental as well as mathematical and computational modeling to study the organization and dynamics of biological systems. They are involved in interdisciplinary collaborations with researchers in biology, bioengineering and related fields. Areas of research involve experimental and theoretical studies of mechanical properties of cells and biomaterials using techniques such as optical tweezers and optical microscopy; modeling studies of cell division, cell motion, polarized growth, and mating; physics of cytoskeletal self-organization; and experimental study of lipid membranes using microfluidics and confocal microscopy.

Computational Physics. Many of the fields of physics research at Lehigh involve the use of state-of-the-art computers to address large-scale computational problems. Researchers in the physics department employ computational approaches to model complex many-body systems in condensed matter, biological, and quantum systems; the detection of variable signals in large astronomical surveys; coarse-grained models of biological systems with molecular dynamics, statistical, and continuum methods. The computational research is performed at both high performance computing facilities on campus and in national facilities.

Condensed Matter Physics. Areas of interest include the optical and electronic properties of defects in semiconductors and insulators; collective dynamics of disordered solids; structural phase transitions in ferroelectrics and superconducting crystals; organic molecular crystals; exciton dynamics, singlet-triplet conversion, and in general the physics of electronic and optoelectronic devices; the quantum physics of matter, fields, and their interactions at the nanoscale; surfaces, interfaces and heterostructures; emergent physics in low-dimensional materials; strongly correlated electronic systems, topological phases of matter, unconventional superconductivity, and classical and quantum phase transitions.

High Energy Nuclear Experimental Physics. Current research involves the study of relativistic heavy-ion collisions at the Solenoidal Tracker at RHIC (STAR) and sPHENIX experiments at Brookhaven National labs. This field of research focuses on the study of matter under extreme conditions of temperature, density, and pressure, where the quarks and gluons that make up normal nuclear matter are no longer confined into hadrons. This deconfined matter is called the quark gluon plasma (QGP), and experiments use high-energy probes, such as particle jets and heavy flavor quarks, to determine how quarks and gluons lose energy in this medium.

High Energy Theory. String theory, quantum field theory and cosmology. Areas of interest include the connection between gravitational theories and quantum field theories, holographic gauge/gravity dualities, the behavior of strongly correlated quantum phases of matter, and the evolution of the early universe.

Nonlinear Optics and Photonics. Research topics include nonlinear light-matter interaction that enables the control of light with light, four-wave mixing, phase conjugation, and wavelength conversion. We develop materials for second- and third-order nonlinear optics in particular organic molecular assemblies, and in general study materials and effects for photonics and optoelectronics. Examples include single crystals in glass, photonic crystals, holey and other specialty fibers, waveguides, resonant Brillouin scattering, and ferroelectric domain patterning for quasi phase matching. There is also considerable work on applications of photonics to biological systems, near-field optics, and thermal radiation.

Plasma Physics. Laboratory studies of collisional and collisionless phenomena in supercritical laser-produced plasmas. Laboratory simulation of supernova emissions in the mid-infrared by excitation of interstellar nano-crystallites by strong shock waves in a new cryogenic diaphragm-less shock tube facility

Soft Condensed Matter and Complex Fluids. Biopolymer networks, biomembranes, and colloidal suspensions are investigated using experimental techniques such as confocal microscopy, laser tweezers, electro-osmotic control, microfluidics, in combination with image analysis and computational modeling. Research areas include phase separation on cell membranes, microrheology of macromolecules and living cells, generalized sedimentation equilibrium of colloidal suspensions, active colloidal suspensions far from equilibrium, diffusion in complex and/or crowded environments, and formation and evolution of nanoscale complexes in solutions.

Statistical Physics. Research includes equilibrium and nonequilibrium fluctuations in gases and liquids; genesis and dynamics of disorder in 2-D solids near percolation threshold; and modeling of transport in disordered metallic solids under thermal forcing.

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. Resources include a machine shop, electronics shop, and networked computer facilities.

Lehigh researchers in astrophysics are involved in a number of worldwide astrophysics surveys and collaborations, including the KELT exoplanet survey, the NASA K2 and TESS missions, LSST, and WFIRST. Lehigh researchers in experimental high energy nuclear physics participate in collaborations affiliated with the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Lab. These include the Solenoidal Tracker at RHIC (STAR) and the sPHENIX collaborations.

Instruments used for experimental studies include a wide variety of laser systems, spectrometers, and microscopes. Examples include femtosecond and picosecond pulsed and dye lasers, various spectrometers (Raman and Fourier-transform), a facility for luminescence microscopy, a cell culture facility, and a laser-tweezers system for studies of cells and complex fluids. The Fairchild Laboratory also houses a processing laboratory where advanced Si devices can be fabricated and studied.

Several physics professors are also members of interdisciplinary initiatives that offer 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. World-class electron microscopy facilities are also available. Members of the physics department also participate in Lehigh's Emulsions Polymer Institute, the Institute for Functional Materials and Devices, and the Institute for Data, Intelligent Systems, and Computation.

Extensive up-to-date computer facilities are available on campus and in the department. High Performance Computing facilities (http://www.lehigh.edu/computing/hpc/), can be accessed directly from graduate student and faculty offices through a high speed backbone. Access to the Extreme Science and Engineering Discovery Environment (XSEDE) is available through computing time allocations to Lehigh faculty.

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 0-2 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 0,4 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 0,4 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 0,3 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 0-2 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 0,4 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.
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)
Can be taken Concurrently: PHY 021, PHY 013
Attribute/Distribution: NS

PHY 031 Introduction to Modern Physics 3 Credits
Experimental basis and historical development of special relativity and quantum mechanics; the Schroedinger equation; one-dimensional problems; angular momentum and the hydrogen atom; many-electron systems; spectra; selected applications.
Prerequisites: PHY 013 or PHY 021
Attribute/Distribution: NS

PHY 120 Physics of Medical Imaging: Ultrasound and Radiography 2 Credits
An introduction and analysis of the physical principles and effects that underlay medical imaging techniques such as those using ultrasound, x-rays or other high-energy radiation. The course will serve as an introduction to intermediate quantum physics and electromagnetism concepts and discuss the effects and data collection techniques that ultimately allow to create an image that a physician can interpret for clinical purposes.
Prerequisites: PHY 021 or PHY 013
Attribute/Distribution: NS

PHY 121 Physics of Medical Imaging: Ultrasound and Radiography, Supplement 1 Credit
A supplementary course taken concurrently with PHY 120 [Physics of Medical Imaging: Ultrasound and Radiography]. Themes pertaining ultrasound and radiography will be covered more in depth, like for example: SPECT- and PET-scans, Beam forming and phased arrays, Dosimetry, Image formation (Radon transform and projection slice theorem).
Prerequisites: PHY 021 or PHY 013
Corequisites: PHY 120
Attribute/Distribution: NS

PHY 122 Physics of Medical Imaging: Magnetic Resonance 2 Credits
An introduction and analysis of the physical principles and effects that underlay medical imaging techniques based on nuclear magnetic resonance, such as MRI (Magnetic Resonance Imaging). The course will serve as an introduction to intermediate/advanced quantum physics and electromagnetism concepts and discuss the effects and data collection techniques that ultimately allow to create an image that a physician can interpret for clinical purposes.
Prerequisites: PHY 021 or PHY 013
Attribute/Distribution: NS

PHY 123 Physics of Medical Imaging: Magnetic Resonance, Supplement 1 Credit
A supplementary course taken concurrently with PHY 122 [Physics of Medical Imaging: Magnetic Resonance]. Themes pertaining magnetic resonance will be covered more in depth, like for example: Fourier analysis in spectroscopy, Advanced techniques in magnetic resonance (fMRI, DTI, mMRI, …).
Prerequisites: PHY 021 or PHY 013
Corequisites: PHY 122
Attribute/Distribution: NS

PHY 142 Special Relativity 3 Credits
A development of the special theory of relativity at an introductory/intermediate level. Starting from the equivalence between inertial reference frames, the course will introduce the Lorentz transformations, space and time in different reference frames, the new relativistic versions of kinematics and mechanics, and the relationship between relativity and electromagnetism. Topics include momentum and energy, four-vectors, acceleration and forces, the relativistic version of Newton's second law, zero-mass particles, and the relation between electric and magnetic fields.
Prerequisites: PHY 013 or PHY 021
Attribute/Distribution: NS

PHY 212 Electricity and Magnetism I 3 Credits
Electrostatics, magnetostatics, and electromagnetic induction.
Prerequisites: (PHY 021 or PHY 013) and MATH 205
Can be taken Concurrently: MATH 205
Attribute/Distribution: NS

PHY 213 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 212
Attribute/Distribution: NS

PHY 215 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) and MATH 205
Can be taken Concurrently: MATH 205
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 and (PHY 022 or CSE 003 or CSE 007)
Attribute/Distribution: NS

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

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 300 Apprentice Teaching 1-4 Credits

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) and (MATH 023 or MATH 033) and PHY 031 and PHY 215
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) and (MATH 023 or MATH 032 or MATH 052)
Attribute/Distribution: NS

PHY 342 (ASTR 342) General Relativity 3 Credits
An introduction to Einstein's theory of general relativity. Topics covered: the geometry of spacetime; curvature and the gravitational field equations; the Schwarzschild and Kerr black holes and more general spacetime geometries; black hole thermodynamics; gravitational waves; the Friedmann–Robertson–Walker geometry and inflationary cosmology; dark energy and the cosmological constant problem.
Prerequisites: (PHY 021) and (MATH 023 or MATH 033) and PHY 215
Can be taken Concurrently: MATH 023, MATH 033, PHY 215
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 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 213 or ECE 203)
Can be taken Concurrently: PHY 213, ECE 203
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 Quantum Mechanics I 3 Credits
Principles and basic applications of quantum mechanics. The Schrödinger equation and one-dimensional problems. Observables as operators; eigenfunctions and eigenvalues. Angular momentum, central potentials, the hydrogen atom, and spin. Addition of angular momentum. Exchange symmetry, Pauli principle, and multi-electron atoms. Selected applications to atoms and molecules, solids, quantum technologies, nuclei, and elementary particles.
Prerequisites: (PHY 031 or CHM 341) and MATH 205
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 and PHY 362
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 II 3 Credits
Applications of quantum mechanics to more complex problems. Bose and Fermi statistics of identical particles. Perturbation theory and applications to atomic structure. Variational method, WKB approximation, and scattering theory. Time-dependent perturbation theory and Fermi's golden rule. Selection of special topics.
Prerequisites: PHY 031 and MATH 205 and PHY 215 and PHY 362
Attribute/Distribution: NS

PHY 380 Introduction to Computational Physics 3 Credits
Introduction to computational modeling of physical systems. Methods for systems of particles and fields with examples drawn from mechanics, chemical kinetics, planetary motion, chaotic dynamics, normal modes and waves, random walks, electrodynamics, biological, thermal and quantum systems. Converting models into well-documented code organized into manageable tasks. Extracting physical insight. Choice of numerical methods considering accuracy, speed, stability, and conservation laws.
Prerequisites: MATH 205
Can be taken Concurrently: MATH 205
Attribute/Distribution: NS

PHY 382 Physics of Cells 3 Credits
This course focuses on the physical principles underlying the organization of living cells, which spans several orders of magnitude in length and time. It provides an introduction to biological physics and relevant concepts of soft-matter physics. Topics include: self-organization of filaments and motor proteins of the cytoskeleton that determine cell shape and motion; the plasma membrane as a fluid responsive to environmental and biochemical signals; biological waves and pattern formation; mathematical modeling of biological systems; experimental methods and image analysis.
Prerequisites: (PHY 010 or PHY 011) and (PHY 013 or PHY 021)
Attribute/Distribution: NS

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

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
A continuation of Phys 424. Relativistic quantum theory of the electron; theory of radiation.
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.

PHY 431 Theory Of Solids 3 Credits
Advanced topics in the theory of the electronic structure of solids. Many-electron theory. Theory of transport phenomena. Magnetic properties, optical properties. Superconductivity. Point imperfections.
Prerequisites: PHY 363 and PHY 424

PHY 442 Statistical Mechanics 3 Credits
General principles of statistical mechanics with application to thermodynamics and the equilibrium properties of matter.
Prerequisites: PHY 340 and PHY 369

PHY 443 Nonequilibrium Statistical Mechanics 3 Credits
A continuation of PHY 442. Applications of kinetic theory and statistical mechanics to nonequilibrium processes; nonequilibrium thermodynamics.
Prerequisites: PHY 442

PHY 446 Atomic and Molecular Physics 3 Credits
Advanced topics in the experimental and theoretical study of atomic and molecular structure. Topics include fine and hyperfine structure, Zeeman effect, interaction of light with matter, multi-electron atoms, molecular spectroscopy, spectral line broadening atom-atom and electron-atom collisions and modern experimental techniques.
Prerequisites: PHY 424

PHY 455 Physics of Nonlinear Phenomena 3 Credits
Basic concepts, theoretical methods of analysis and experimental development in nonlinear phenomena and chaos. Topics include nonlinear dynamics, including period-multiplying routes to chaos and strange attractors, fractal geometry and devil's staircase. Examples of both dissipative and conservative systems will be drawn from fluid flows, plasmas, nonlinear optics, mechanics and waves in disordered media. Must have graduate standing in science or engineering, or consent of the chairman of the department.

PHY 462 Theories of Elementary Particle Interactions 3 Credits
Relativistic quantum theory with applications to the strong, electromagnetic and weak interactions of elementary particles.
Prerequisites: PHY 425

PHY 472 Special Topics In Physics 1-3 Credits
Selected topics not sufficiently covered in other courses.
Repeat Status: Course may be repeated.

PHY 474 Seminar In Modern Physics 3 Credits
Discussion of important advances in experimental physics.
Repeat Status: Course may be repeated.

PHY 475 Seminar In Modern Physics 3 Credits
Discussion of important advances in theoretical physics.
Repeat Status: Course may be repeated.

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.