

# PHYSICS

Department Website: <http://physics.uchicago.edu>

## PROGRAM OF STUDY

Physics is concerned with the study of space and time, matter and energy, forces and fields, and the fundamental laws that relate them to the universe. The undergraduate curriculum in the Department of Physics covers the broad fundamentals necessary for further study in theoretical or experimental physics, as well as allied fields in science and engineering. The physics major offers both BA and BS degrees.

Students who are majoring in other fields of study may also complete a minor in physics. Information follows the description of the major.

## PROGRAM REQUIREMENTS

### Courses

The curriculum leading to the BA degree in physics is designed for maximum flexibility consistent with a thorough coverage of the essential principles of physics. Degree requirements include introductory and advanced physics and mathematics courses, as well as physics electives that allow students to pursue specific interests.

The curriculum leading to the BS degree in physics includes all the requirements of the BA degree plus additional courses in electricity and magnetism, quantum mechanics, and experimental physics. Its more extensive coverage of these topics makes it particularly well-suited for students planning for graduate study in physics.

Students who plan to major in physics are encouraged to start course work in their first year. However, the program can be completed in three years, so one could start physics in the second year without delaying graduation. Two of the physics and two of the mathematics courses can be designated as general education courses, with 15 (BA) or 18 (BS) courses remaining to fulfill the major.

In general, students should take the most advanced courses for which they have the appropriate prerequisites. Entering students will be given a placement for either PHYS 13100 Mechanics or PHYS 14100 Honors Mechanics based on their mathematics and physics background. Either course is appropriate for students planning to major (or minor) in physics.

### Mathematics

The mathematics requirement is a Mathematical Methods sequence, MATH 18300-18400-18500-18600 Mathematical Methods in the Physical Sciences I-II-III-IV. Alternatively, students may use an Analysis sequence (MATH 20300-20400-20500 Analysis in  $\mathbb{R}^n$  I-II-III or higher) and MATH 20250 Abstract Linear Algebra, though they may subsequently need to acquire certain math tools, as needed, on their own.

## SUMMARY OF REQUIREMENTS FOR THE BA IN PHYSICS

### GENERAL EDUCATION

One of the following sequences:	200
PHYS 13100-13200	Mechanics; Electricity and Magnetism
PHYS 14100-14200	Honors Mechanics; Honors Electricity and Magnetism *
One of the following sequences:	200
MATH 15100-15200	Calculus I-II *
MATH 16100-16200	Honors Calculus I-II
Total Units	400

### MAJOR

One of the following:	100
PHYS 13300	Waves, Optics, and Heat
PHYS 14300	Honors Waves, Optics, and Heat *
One of the following sequences:	400
MATH 18300-18400-18500-18600	Mathematical Methods in the Physical Sciences I-II-III-IV
MATH 20300 & MATH 20400 & MATH 20500 & MATH 20250	Analysis in $\mathbb{R}^n$ I and Analysis in $\mathbb{R}^n$ II and Analysis in $\mathbb{R}^n$ III and Abstract Linear Algebra
PHYS 18500	Intermediate Mechanics
PHYS 21101-21102	Experimental Physics I-II

PHYS 22500	Intermediate Electricity and Magnetism I	100
PHYS 23410-23510	Quantum Mechanics I-II	200
PHYS 27900	Statistical and Thermal Physics	100
Three electives (to be selected from list of approved courses)		300
Total Units		1500

\* Credit may be granted by examination.

## SUMMARY OF REQUIREMENTS FOR THE BS IN PHYSICS

### GENERAL EDUCATION

One of the following sequences:		200
PHYS 13100-13200	Mechanics; Electricity and Magnetism	
PHYS 14100-14200	Honors Mechanics; Honors Electricity and Magnetism *	
One of the following sequences:		200
MATH 15100-15200	Calculus I-II *	
MATH 16100-16200	Honors Calculus I-II	
Total Units		400

### MAJOR

One of the following:		100
PHYS 13300	Waves, Optics, and Heat	
PHYS 14300	Honors Waves, Optics, and Heat *	
One of the following sequences:		400
MATH 18300-18400-18500-18600	Mathematical Methods in the Physical Sciences I-II-III-IV	
MATH 20300 & MATH 20400 & MATH 20500 & MATH 20250	Analysis in $R^n$ I and Analysis in $R^n$ II and Analysis in $R^n$ III and Abstract Linear Algebra	
PHYS 18500	Intermediate Mechanics	100
PHYS 21101-21102-21103	Experimental Physics I-II-III	300
PHYS 22500-22700	Intermediate Electricity and Magnetism I-II	200
PHYS 23410-23510-24310	Quantum Mechanics I-II-III	300
PHYS 27900	Statistical and Thermal Physics	100
Three electives (to be selected from list of approved courses)		300
Total Units		1800

\* Credit may be granted by examination.

### Electives

In addition to specified course work, the physics major requires three electives. These electives may be selected from the following courses:

All 20000-level physics courses (except PHYS 29100-29200-29300, and PHYS 29700)

Any of the following courses offered in other departments:	
ASTR 21100	Computational Techniques in Astrophysics
ASTR 23900	Physics of Galaxies
ASTR 24100	The Physics of Stars
ASTR 24300	Cosmological Physics
ASTR 24500	The Physics of the Dark Universe
ASTR 25400	Radiation Processes in Astrophysics
ASTR 25800	Astrophysics of Exoplanets
BIOS 21506	Biological Physics
BIOS 29326	Introduction to Medical Physics and Medical Imaging
CHEM 26300	Chemical Kinetics and Dynamics
CHEM 26800	Quantum Molecular and Materials Modeling
CMSC 22880	Introduction to Quantum Computing

CMSC 23710	Scientific Visualization
CMSC 25025	Machine Learning and Large-Scale Data Analysis
CMSC 25400	Machine Learning
CMSC 25500	Introduction to Neural Networks
CMSC 28510	Introduction to Scientific Computing
CMSC 28515	Introduction to Numerical Partial Differential Equations
DATA 22100	Introduction to Machine Learning: Concepts and Applications
DATA 23100	Machine Learning Fundamentals: Theory and Practice
GEOS 21200	Physics of the Earth
GEOS 24220	Climate Foundations
GEOS 24230	Geophysical Fluid Dynamics: Foundations
GEOS 24240	Geophysical Fluid Dynamics: Rotation and Stratification
GEOS 24250	Geophysical Fluid Dynamics: Understanding the Motions of the Atmosphere and Oceans
GEOS 24550	Ocean Circulation
MATH 23500	Markov Chains, Martingales, and Brownian Motion
MATH 26200	Point-Set Topology
MATH 27000	Basic Complex Variables
MATH 27200	Basic Functional Analysis
MATH 27300	Basic Theory of Ordinary Differential Equations
MATH 27400	Introduction to Differentiable Manifolds and Integration on Manifolds
MATH 27500	Basic Theory of Partial Differential Equations
MATH 27600	Dynamical Systems
MENG 21100	Principles of Engineering Analysis I
MENG 21200	Principles of Engineering Analysis II
MENG 21500	Molecular Engineering Transport Phenomena
MENG 24200	Molecular Transport Phenomena II: Fluid Flow and Convective Transport Processes
MENG 26300	Engineering Electrodynamics
MENG 26400	Quantum Computation
MENG 26500	Foundations of Quantum Optics
STAT 23400	Statistical Models and Methods
or STAT 24400	Statistical Theory and Methods I
or STAT 24410	Statistical Theory and Methods Ia
STAT 24500	Statistical Theory and Methods II
or STAT 24510	Statistical Theory and Methods IIa
or other courses approved by the program chair for physics	

### Sample Programs

An example of what the major might look like is shown below.

In the first year, a physics sequence is taken concurrently with Mathematical Methods:

First Year		
Autumn Quarter	Winter Quarter	Spring Quarter
PHYS 13100 or 14100	PHYS 13200 or 14200	PHYS 13300 or 14300
MATH 18300	MATH 18400	MATH 18500

The Mathematical Methods sequence could also start in Winter Quarter, if additional exposure to calculus is needed.

The remaining required courses are typically distributed over the next three years, like so:

Second Year		
Autumn Quarter	Winter Quarter	Spring Quarter
PHYS 18500	PHYS 23410	PHYS 23510
MATH 18600		
Third Year		
Autumn Quarter	Winter Quarter	Spring Quarter
PHYS 24310**	PHYS 22500	PHYS 22700**

PHYS 21101                      PHYS 21102                      PHYS 21103\*\*  
 Fourth Year  
 Autumn Quarter  
 PHYS 27900

where the additional courses required for a BS are denoted by \*\*.

In addition, three electives (selected from a list of approved courses) must be taken. In deciding when to take electives, students should be mindful of any course prerequisites.

The required laboratory sequence PHYS 21101-21102 or PHYS 21101-21102-21103 is a study of experimental physics. It is recommended, but not required, that Experimental Physics be taken in the third year.

Progress through the physics program can be accelerated by taking PHYS 22500 (<http://collegecatalog.uchicago.edu/search/?P=PHYS%2022500>)-22700 (<http://collegecatalog.uchicago.edu/search/?P=PHYS%2022700>) in the second year, and PHYS 27900 in the third year. This provides more options in the third and fourth years for electives, as well as research or graduate course work. Note that it is possible to complete all program requirements in three years.

Finally, the sample program shown here is only meant to be illustrative. Students are encouraged to speak with the departmental counselors in planning individual programs, especially regarding selection of mathematics courses and program electives.

### Introductory Course

The introductory course for students in the physical sciences is divided into two variants—PHYS 13100-13200-13300 Mechanics; Electricity and Magnetism; Waves, Optics, and Heat and PHYS 14100-14200-14300 Honors Mechanics; Honors Electricity and Magnetism; Honors Waves, Optics, and Heat—so students may learn with others who have comparable physics and mathematics backgrounds. The essential physics content of these two sequences is the same, but the 140s sequence covers material at a higher mathematical level. Both PHYS 130s and PHYS 140s prepare students for further courses in the physics major or minor.

The Mathematical Methods sequence MATH 18300-18400-18500-18600 Mathematical Methods in the Physical Sciences I-II-III-IV would be taken concurrently, with MATH 18300 starting in Autumn or Winter Quarter of first year. Alternatively, the Mathematical Methods sequence may be replaced with MATH 20300-20400-20500 Analysis in Rn I-II-III (or higher) and MATH 20250. Depending on math background, some portion of the first-year calculus sequence MATH 15100-15200 or MATH 16100-16200 may be needed prior to taking the Mathematical Methods sequence.

First-year students are placed into either PHYS 13100 or PHYS 14100 based on Advanced Placement test scores. Subsequent adjustments in physics placement can be made by consulting the undergraduate program chair during Orientation week. Transfer students who have satisfactorily completed calculus-based introductory physics courses at another university may be granted appropriate transfer credit upon petition to, and approval by, the College.

Another introductory sequence, PHYS 12100-12200-12300, is intended for students pursuing studies in biology or medicine. The prerequisite is two quarters of calculus and completion of general chemistry. While topics are similar to the 130s and 140s sequences, PHYS 120s cannot serve as a prerequisite for further courses in physics, and thus cannot be used for the physics major or minor.

For PHYS 13100 and PHYS 13200, a grade of at least C- is required to take the next course in the sequence. For a passing grade below C-, the student will need to obtain permission from the undergraduate program chair before enrolling.

A student who completes PHYS 14100 or PHYS 14200 with a grade below C is normally required to move to PHYS 13200 or PHYS 13300 the following quarter. Petitions for a waiver of this requirement must be presented to the undergraduate program chair before the second day of the succeeding course. A student who receives an A or A- in PHYS 13100 may petition the undergraduate program chair to move to PHYS 14200.

### Advanced Placement

Students who took one or both Physics C Advanced Placement examinations prior to matriculation in the College may receive credit for PHYS 12100 and/or PHYS 12200. Consult the section on Advanced Placement Credit (<http://collegecatalog.uchicago.edu/thecollege/examinationcreditandtransfercredit/>) in this catalog for more information.

### Accreditation

Accreditation examinations are administered for the content of PHYS 12100-12200-12300 and PHYS 14100-14200-14300. The first examination may be taken by incoming students only at the time of matriculation in the College. Students who pass the first examination (for PHYS 12100 or PHYS 14100) will receive credit for the lecture part of the course only and will then be invited to try the next examination of the sequence. All students who receive advanced standing on the basis of a physics accreditation examination are interviewed by

the undergraduate program chair to determine the extent of their lab experience. Additional laboratory work may be required.

### GRADING

All regular (non-research) physics courses must be taken for quality grades. All courses used to satisfy prerequisites must be taken for quality grades. The Department of Physics requires students to pass PHYS 13100-13200-13300 or PHYS 14100-14200-14300, and PHYS 18500-23410-23510 with an average of 2.0 or higher to continue in the program.

### OPPORTUNITIES FOR PARTICIPATION IN RESEARCH

The physics program offers unique opportunities for College students to become actively involved in the research being conducted by faculty of the department. Interested students are welcome to consult with the departmental counselors. The focus of much of the undergraduate research is structured around the Bachelor's Thesis (PHYS 29100-29200-29300). Alternatively, third- or fourth-year students majoring in physics may register for research for academic credit (PHYS 29700). In addition to these formal arrangements, students at any level may become involved in research by working in a faculty member's lab or research group on an extracurricular basis.

### HONORS

The BA and BS degrees can be awarded with Special Honors. Requirements for both are as follows:

- 1) a minimum GPA of 3.3 in the courses listed under Major in the preceding Summary of Requirements sections.
- 2) completion of PHYS 29100-29200-29300 with a grade of B or higher, based on a bachelor's thesis describing an approved research project completed during the year.

### MINOR PROGRAM IN PHYSICS

The minor in physics is designed to present a coherent program of study to students with a strong interest in physics but insufficient time to pursue the major. The courses required for the minor are:

One of the following:		100
PHYS 13300	Waves, Optics, and Heat	
PHYS 14300	Honors Waves, Optics, and Heat	
One of the following:		400
MATH 18300-18400-18500-18600	Mathematical Methods in the Physical Sciences I-II-III-IV	
MATH 20300 & MATH 20400 & MATH 20500 & MATH 20250	Analysis in $R^n$ I and Analysis in $R^n$ II and Analysis in $R^n$ III and Abstract Linear Algebra	
PHYS 18500	Intermediate Mechanics	100
PHYS 23410	Quantum Mechanics I	100
Two electives, at least one of which is:		200
PHYS 22500	Intermediate Electricity and Magnetism I	
PHYS 23510	Quantum Mechanics II	
PHYS 27900	Statistical and Thermal Physics	
The second elective may be any course that is required by the major or can be used as an elective for the major.		
<hr/> Total Units		900

The mathematics requirement for the minor is identical to the requirement for the major; please consult the description of the major for more information. Please note that any courses in the mathematics requirement being used to satisfy the requirements of a major or another minor will be waived. Consequently, the number of courses needed for the minor will vary between five and nine.

If PHYS 13300/14300 is being used to satisfy the requirements of a major, it must be replaced by another course approved by the undergraduate program chair.

Students who elect the minor program in physics must meet with the physics undergraduate program chair before the end of Spring Quarter of their third year to declare their intention to complete the minor. The approval of the program chair for the minor program should be submitted to a student's College adviser by the deadline above on a form obtained from the College adviser. Courses for the minor are chosen in consultation with the program chair.

Courses in the minor (1) may not be double counted with the student's major(s) or with other minors and (2) may not be counted toward general education requirements. Courses in the minor must be taken for quality grades, and students must have a GPA of 2.0 or higher in the minor. More than half of the requirements for the minor must be met by registering for courses bearing University of Chicago course numbers.

## PHYSICS COURSES

### **PHYS 12100-12200-12300. General Physics I-II-III.**

This is a one-year sequence in the fundamentals of physics for students in the biological sciences and pre-medical studies. Univariable calculus will be used as needed. Where appropriate, attention will be drawn to interdisciplinary applications. The first two courses meet the general education requirement in physical sciences. (L)

#### **PHYS 12100. General Physics I. 100 Units.**

This course covers Newtonian mechanics and fluid dynamics. (L)

Terms Offered: Autumn

Prerequisite(s): MATH 13200 or 15200 or 16200; CHEM 11300 or 12300.

#### **PHYS 12200. General Physics II. 100 Units.**

This course covers electric and magnetic fields. (L).

Terms Offered: Winter

Prerequisite(s): PHYS 12100

#### **PHYS 12300. General Physics III. 100 Units.**

This course covers waves, optics, and modern physics. (L)

Terms Offered: Spring

Prerequisite(s): PHYS 12200

### **PHYS 13100-13200-13300. Mechanics; Electricity and Magnetism; Waves, Optics, and Heat.**

This is a one-year introductory sequence in physics for students in the physical sciences. Univariable calculus will be used extensively. The first two courses meet the general education requirement in physical sciences. (L)

#### **PHYS 13100. Mechanics. 100 Units.**

Topics include particle motion, Newton's Laws, work and energy, systems of particles, rigid-body motion, gravitation, oscillations, and special relativity. (L)

Instructor(s): Staff Terms Offered: Autumn

Prerequisite(s): MATH 13300 or 15100 or 16100 (may be concurrent with MATH 15100 or 16100).

#### **PHYS 13200. Electricity and Magnetism. 100 Units.**

Topics include electric fields, Gauss' law, electric potential, capacitors, DC circuits, magnetic fields, Ampere's law, induction, Faraday's law, AC circuits, Maxwell's equations, and electromagnetic waves. (L)

Terms Offered: Winter

Prerequisite(s): Minimum grade of C- in PHYS 13100 or 14100, or consent of instructor. MATH 13300 or 15200 or 16200 (may be concurrent with MATH 15200 or 16200).

#### **PHYS 13300. Waves, Optics, and Heat. 100 Units.**

Topics include mechanical waves, sound, light, polarization, reflection and refraction, interference, diffraction, geometrical optics, heat, kinetic theory, and thermodynamics. (L)

Instructor(s): Staff Terms Offered: Spring

Prerequisite(s): Minimum grade of C- in PHYS 13200 or 14200, or consent of instructor. MATH 13300 or 15300 or 16300 or 18300 (may be concurrent with MATH 15300 or 16300 or 18300).

### **PHYS 14100-14200-14300. Honors Mechanics; Honors Electricity and Magnetism; Honors Waves, Optics, and Heat.**

This is a one-year introductory sequence in physics for students in the physical sciences. A strong background in univariable calculus is assumed. Multivariable and vector calculus will be introduced and used extensively. The first two courses meet the general education requirement in physical sciences. (L)

#### **PHYS 14100. Honors Mechanics. 100 Units.**

Topics include particle motion, Newton's Laws, work and energy, systems of particles, rigid-body motion, gravitation, oscillations, and special relativity. (L)

Instructor(s): Staff Terms Offered: Autumn

Prerequisite(s): Placement required.

#### **PHYS 14200. Honors Electricity and Magnetism. 100 Units.**

Topics include electric fields, Gauss' law, electric potential, capacitors, DC circuits, magnetic fields, Ampere's law, induction, Faraday's law, AC circuits, Maxwell's equations, and electromagnetic waves. (L)

Instructor(s): Staff Terms Offered: Winter

Prerequisite(s): PHYS 14100

#### **PHYS 14300. Honors Waves, Optics, and Heat. 100 Units.**

Topics include mechanical waves, sound, light, polarization, reflection and refraction, interference, diffraction, geometrical optics, heat, kinetic theory, and thermodynamics. (L)

Instructor(s): Staff Terms Offered: Spring

Prerequisite(s): PHYS 14200

**PHYS 18500. Intermediate Mechanics. 100 Units.**

Topics include a review of Newtonian mechanics, the calculus of variations, Lagrangian and Hamiltonian mechanics, generalized coordinates, canonical momenta, phase space, constrained systems, central-force motion, non-inertial reference frames, and rigid-body motion.

Instructor(s): Staff Terms Offered: Autumn

Prerequisite(s): PHYS 13100 or 14100; MATH 18400 or 20300 (may be concurrent with MATH 20300).

**PHYS 21101-21102-21103. Experimental Physics I-II-III.**

This is a year-long laboratory sequence, offering experiments in atomic, molecular, solid-state, nuclear, and particle physics. Additional material, as needed, is presented in supplemental lectures. Content varies from quarter to quarter. (L)

Note(s): Open only to students who are majoring in Physics.

**PHYS 21101. Experimental Physics I. 100 Units.**

This is a year-long laboratory sequence, offering experiments in atomic, molecular, solid-state, nuclear, and particle physics. Additional material, as needed, is presented in supplemental lectures. Content varies from quarter to quarter.

Instructor(s): Staff Terms Offered: Autumn

Prerequisite(s): PHYS 23510

**PHYS 21102. Experimental Physics II. 100 Units.**

A continuation of the year-long laboratory sequence.

Terms Offered: Winter

Prerequisite(s): PHYS 21101

**PHYS 21103. Experimental Physics III. 100 Units.**

A continuation of the year-long laboratory sequence.

Terms Offered: Spring

Prerequisite(s): PHYS 21102

**PHYS 21400. Creative Machines and Innovative Instrumentation. 100 Units.**

An understanding of the techniques, tricks, and traps of building creative machines and innovative instrumentation is essential for a range of fields from the physical sciences to the arts. In this hands-on, practical course, you will design and build functional devices as a means to learn the systematic processes of engineering and fundamentals of design and construction. The kinds of things you will learn may include mechanical design and machining, computer-aided design, rapid prototyping, circuitry, electrical measurement methods, and other techniques for resolving real-world design problems. In collaboration with others, you will complete a mini-project and a final project, which will involve the design and fabrication of a functional scientific instrument. The course will be taught at an introductory level; no previous experience is expected. The iterative nature of the design process will require an appreciable amount of time outside of class for completing projects. The course is open to undergraduates in all majors (subject to the pre-requisites), as well as Master's and Ph.D. students.

Instructor(s): Wakely (Autumn Quarter); Juan Estrada (Winter Quarter); Derek Buzasi (Spring Quarter) Terms Offered: Autumn Spring Winter

Prerequisite(s): PHYS 12200 or PHYS 13200 or PHYS 14200; or CMSC 12100 or CMSC 12200 or CMSC 12300; or consent of instructor.

Equivalent Course(s): ASTR 21400, CMSC 21400, PSMS 31400, ASTR 31400

**PHYS 22500-22700. Intermediate Electricity and Magnetism I-II.**

This is a two-quarter sequence on static and time-varying electric and magnetic fields.

**PHYS 22500. Intermediate Electricity and Magnetism I. 100 Units.**

Topics include electrostatics and magnetostatics, boundary-value problems, and electric and magnetic fields in matter.

Terms Offered: Winter

Prerequisite(s): PHYS 13200 or 14200; MATH 18500 or 20250 (may be concurrent with MATH 20250)

**PHYS 22700. Intermediate Electricity and Magnetism II. 100 Units.**

Topics include electromagnetic induction, electromagnetic waves, and radiation.

Terms Offered: Spring

Prerequisite(s): PHYS 22500

**PHYS 22600. Electronics. 100 Units.**

This hands-on experimental course is intended to develop confidence, understanding, and design ability in modern electronics. It is not a course in the physics of semiconductors. In two lab sessions a week, we explore the properties of diodes, transistors, amplifiers, operational amplifiers, oscillators, field effect transistors, logic gates, digital circuits, analog-to-digital and digital-to-analog converters, phase-locked loops, and more. Lectures supplement the lab. (L)

Instructor(s): Staff Terms Offered: Spring

Prerequisite(s): PHYS 12200 or 13200 or 14200

**PHYS 23410-23510-24310. Quantum Mechanics I-II-III.**

This is a three-quarter sequence that, starting from basic postulates, develops the formalism of quantum mechanics and uses it to study atomic phenomena.

**PHYS 23410. Quantum Mechanics I. 100 Units.**

A study of wave-particle duality leading to the basic postulates of quantum mechanics is presented. Topics include the uncertainty principle, applications of the Schrödinger equation in one and three dimensions, the quantum harmonic oscillator, rotational invariance and angular momentum, the hydrogen atom, and spin.

Terms Offered: Winter

Prerequisite(s): PHYS 13300 or 14300; MATH 18600 or 20250 (may be concurrent with MATH 18600 or 20250).

**PHYS 23510. Quantum Mechanics II. 100 Units.**

A review of quantum mechanics is presented, with emphasis on Hilbert space, observables, and eigenstates. Topics include spin and angular momentum, time-independent perturbation theory, fine and hyperfine structure of hydrogen, the Zeeman and Stark effects, many-electron atoms, molecules, the Pauli exclusion principle, and radiative transitions.

Terms Offered: Spring

Prerequisite(s): PHYS 23410

**PHYS 24310. Advanced Quantum Mechanics. 100 Units.**

This course will cover several topics that further develop and apply the formalism of quantum mechanics. The first main topic involves electromagnetic effects in quantum mechanics including the role of gauge invariance, the Aharonov-Bohm effect, Landau levels, and paramagnetic and diamagnetic effects. The second main topic is scattering in three dimensions including the Born approximation, partial wave analysis and phase shifts, and the optical theorem. Depending on the time available and the interests of the students and instructor, other topics might include the adiabatic approximation and Berry's phase, symmetries in quantum mechanics, and the path integral formulation of quantum mechanics.

Terms Offered: Autumn

Prerequisite(s): PHYS 23510

**PHYS 23600. Solid State Physics. 100 Units.**

Topics include a review of quantum statistics, crystal structure and crystal binding, lattice vibrations and phonons, liquid helium, the free-electron model of metals, the nearly-free-electron model, semi-conductors, and optical properties of solids.

Instructor(s): Staff Terms Offered: Winter

Prerequisite(s): PHYS 23510; PHYS 27900

**PHYS 23700. Nuclei and Elementary Particles. 100 Units.**

This course covers topics such as nuclear structure, processes of transformation, observables of the nucleus, passage of nuclear radiation through matter, accelerators and detectors, photons, leptons, mesons, and baryons, hadronic interactions, and the weak interaction.

Instructor(s): Staff Terms Offered: Winter

Prerequisite(s): PHYS 23510

**PHYS 24510. Introduction to Quantum Field Theory. 100 Units.**

This course is an introduction to the techniques and ideas of relativistic quantum field theory. Topics to be covered include a review of relativistic notation and Lorentz invariance, quantization of scalar and electromagnetic fields, radiative transitions in atomic physics, Green's functions and causality. Additional topics may include the Dirac equation and quantization of fermion fields, the path integral formulation of quantum mechanics, and perturbation theory with Feynman diagrams. The course will end with a brief overview of the Standard Model of particle physics and ideas for what lies beyond the Standard Model.

Terms Offered: Spring

Prerequisite(s): PHYS 22700 and 23510 (may be concurrent with 22700)

**PHYS 25000. Computational Physics. 100 Units.**

This course introduces the use of computers in the physical sciences. After an introduction to programming basics, we cover numerical solutions to fundamental types of problems, including cellular automata, artificial neural networks, computer simulations of complex systems, and finite element analysis. Additional topics may include an introduction to graphical programming, with applications to data acquisition and device control. (L)

Instructor(s): Staff Terms Offered: Autumn

Prerequisite(s): PHYS 13300 or 14300 required; knowledge of computer programming not required

**PHYS 26400. Spacetime and Black Holes. 100 Units.**

This course is an introduction to general relativity, focusing on metrics and geodesics, and treating gravity as the curvature of four-dimensional spacetime. It will begin by fully exploring special relativity, and will then introduce the basic tools of physics in curved spacetime. It will also study black holes, including aspects of the event horizon and singularity, and the properties of orbits in black hole spacetimes.

Instructor(s): Staff Terms Offered: Autumn

Prerequisite(s): PHYS 18500 or consent of instructor

**PHYS 27900. Statistical and Thermal Physics. 100 Units.**

This course develops a statistical description of physical systems. Topics include elements of probability theory, equilibrium and fluctuations, thermodynamics, canonical ensembles, the equipartition theorem, quantum statistics of ideal gases, and kinetic theory.

Instructor(s): Staff Terms Offered: Autumn

Prerequisite(s): PHYS 23510

**PHYS 29100-29200-29300. Bachelor's Thesis I-II-III.**

This year-long sequence of courses is designed to involve the student in current research. Over the course of the year, the student works on a research project in physics or a closely related field, leading to the writing of a bachelor's thesis. A student who submits a satisfactory thesis, earns a grade of B or higher based on the project, and achieves a GPA of 3.3 or higher in courses required for the major is eligible to receive a BA or BS with honors. The project may be one suggested by the instructor or one proposed by the student and approved by the instructor. In either case, all phases of the project (including the literature search, design and construction of the experiments, and analysis) must be done by the student. The instructor and faculty adviser, as well as members of the adviser's research group, are available for consultation. Note: Students are required to submit the College Reading and Research Course Form in Autumn Quarter. Students receive a grade in each quarter of registration: P/F grading in Autumn and Winter Quarters, and a quality grade in Spring Quarter.

**PHYS 29100. Bachelor's Thesis I. 100 Units.**

Students are required to submit the College Reading and Research Course Form. P/F grading.

Terms Offered: Autumn

Prerequisite(s): Open to students who are majoring in Physics with fourth-year standing and consent of instructor.

**PHYS 29200. Bachelor's Thesis II. 100 Units.**

P/F grading.

Terms Offered: Winter

Prerequisite(s): PHYS 29100

**PHYS 29300. Bachelor's Thesis III. 100 Units.**

Quality grading.

Terms Offered: Spring

Prerequisite(s): PHYS 29200

**PHYS 29700. Participation in Research. 100 Units.**

By mutual agreement, students work in a faculty member's research group. Participation in research may take the form of independent work (with some guidance) on a small project, or of assistance in research to an advanced graduate student or research associate. A written report must be submitted at the end of the quarter. Students may register for PHYS 29700 for as many quarters as they wish; students need not remain with the same faculty member each quarter. (L)

Terms Offered: Autumn Spring Summer Winter

Prerequisite(s): Consent of instructor and departmental counselor. Open to students who are majoring in Physics with third- or fourth-year standing.

Note(s): Students are required to submit the College Reading and Research Course Form. May be taken for P/F grading with consent of instructor.

