

# Physics

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

## Program of Study

Physics is concerned with the study of matter, energy, forces, and their interaction in the world and universe around us. The undergraduate curriculum in the Department of Physics leading to the BA in physics includes a strong emphasis on experiment and covers the broad fundamentals necessary for graduate study in theoretical physics, experimental physics, or astronomy and astrophysics, as well as some fields of engineering and many interdisciplinary specialties requiring a strong technical background (e.g., biophysics, medical physics, atmospheric and environmental sciences).

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.

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 sixteen 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 calculus sequence (MATH 15100-MATH 15200-MATH 15300 or MATH 16100-MATH 16200-MATH 16300) followed by PHYS 22100. As an alternative to PHYS 22100, students taking an Analysis sequence (MATH 20300-MATH 20400-MATH 20500 or MATH 20700-MATH 20800-MATH 20900) may substitute MATH 20500 or MATH 20900 for PHYS 22100, though they will subsequently need to acquire certain math tools, as needed, on their own. However, students interested in pursuing further study in physics and mathematics should consider taking both PHYS 22100 and an Analysis sequence.

But please note that for students starting their program with the PHYS 13100-PHYS 13200-PHYS 13300 sequence, the MATH 15300/MATH 16300 requirement is replaced by PHYS 22000. This course in mathematical methods introduces tools typically used in the PHYS 14100-PHYS 14200-PHYS 14300 sequence, and ensures that a student taking PHYS 13100-PHYS 13200-PHYS 13300 will possess the mathematical background needed for subsequent physics course work.

Finally, entering students placing into MATH 13100 should consult the undergraduate program chair to plan a program of study.

## Summary of Requirements

### GENERAL EDUCATION

One of the following sequences:		200
PHYS 13100-13200	Mechanics; Electricity and Magnetism	
PHYS 14100 & PHYS 14200	Honors Mechanics and 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
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### MAJOR

One of the following:		100
PHYS 13300	Waves, Optics, and Heat	
PHYS 14300	Honors Waves, Optics, and Heat *	
One of the following:		100
MATH 15300	Calculus III *	
MATH 16300	Honors Calculus III	
PHYS 22000	Introduction to Mathematical Methods in Physics	

Note: students in PHYS 13300 must take PHYS 22000.

One of the following:		100
PHYS 22100	Mathematical Methods in Physics	
MATH 20500	Analysis in Rn III	
MATH 20900	Honors Analysis in Rn III	
PHYS 15400	Modern Physics	100
PHYS 18500	Intermediate Mechanics	100
PHYS 23400-23500	Quantum Mechanics I-II	200
PHYS 21101-21102-21103	Experimental Physics I-II-III	300
PHYS 22500-22700	Intermediate Electricity and Magnetism I-II	200
PHYS 19700	Statistical and Thermal Physics	100
Three electives (to be selected from list of approved courses)		300
Total Units		1600

\* 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:		
ASTR 24100	The Physics of Stars †	
ASTR 23900	Physics of Galaxies †	
or ASTR 24200	The Physics of Galaxies and the Universe	
ASTR 24300	Cosmological Physics †	
ASTR 25400	Radiation Processes in Astrophysics †	
ASTR 25800	Astrophysics of Exoplanets	
BIOS 29326	Introduction to Medical Physics and Medical Imaging	
CHEM 26300	Chemical Kinetics and Dynamics	
CHEM 26800	Computational Chemistry and Biology	
CMSC 23710	Scientific Visualization	
CMSC 28510	Introduction to Scientific Computing	
GEOS 21200	Physics of the Earth	
GEOS 23200	Climate Dynamics of the Earth and Other Planets	
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	
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	
MENG 23700	Quantum Computation	
MENG 26020	Engineering Electrodynamics	
MENG 26101	Transport Phenomena I: Forces and Flows	
MENG 26102	Transport Phenomena II	
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

† Cannot be counted toward electives if used to satisfy requirements for the specialization in astrophysics.

### Sample Programs

The sample programs below illustrate different paths for fulfilling requirements for the physics major.

In the first example, the Honors physics sequence PHYS 14100-14200-14300 is taken concurrently with calculus:

First Year			
Autumn Quarter	Units	Winter Quarter	Units
PHYS 14100	100	PHYS 14200	100
MATH 15100 or 16100	100	MATH 15200 or 16200	100
	200		200
			200

Total Units: 600

The next example shows a PHYS 13100-13200-13300 pathway. Here, the required PHYS 22000 course replaces the third quarter of calculus.

First Year			
Autumn Quarter	Units	Winter Quarter	Units
PHYS 13100	100	PHYS 13200	100
MATH 15100 or 16100	100	MATH 15200 or 16200	100
	200		200
			200

Total Units: 600

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

Second Year			
Autumn Quarter	Units	Winter Quarter	Units
PHYS 15400	100	PHYS 18500	100
PHYS 22100	100		
	200		100
			100

  

Third Year			
Autumn Quarter	Units	Winter Quarter	Units
PHYS 23500	100	PHYS 22500	100
PHYS 21101	100	PHYS 21102	100
	200		200
			200

  

Fourth Year	
Autumn Quarter	Units
PHYS 19700	100
	100

Total Units: 1100

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 21101-21102-21103 is a year-long study of experimental physics. It is recommended, but not required, that Experimental Physics be taken in the third year, concurrent with PHYS 23500.

Progress through the physics program can be accelerated by "doubling up" on some of the required courses. For example, PHYS 23500 and PHYS 19700 may be taken concurrently in the third year, and PHYS 22500/PHYS 22700 may be concurrent with PHYS 18500/PHYS 23400 in the second 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 programs shown here are 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-PHYS 13200-PHYS 13300 and PHYS 14100-PHYS 14200-PHYS 14300—so students may learn with others who have comparable physics and mathematics backgrounds. The co-requisite for both is a first-year calculus sequence: MATH 15100-MATH 15200-MATH 15300 or MATH 16100-MATH 16200-MATH 16300 (or completion of MATH 13100-MATH 13200-MATH 13300). 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.

First-year students are assigned to either PHYS 13100 or PHYS 14100 based on Advanced Placement test scores. In addition, physics placement may be adjusted by consulting the undergraduate program chair (KPTC 205) 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 program chair.

Another introductory sequence, PHYS 12100-PHYS 12200-PHYS 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.

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 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 in this catalog for more information.

### Accreditation

Accreditation examinations are administered for the content of PHYS 12100-PHYS 12200-PHYS 12300 and PHYS 14100-PHYS 14200-PHYS 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-PHYS 13200-PHYS 13300-PHYS 14100-PHYS 14200-PHYS 14300, PHYS 15400, PHYS 18500, and PHYS 23400 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-PHYS 29200-PHYS 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

There are two routes to receiving a BA with honors. Both require a minimum GPA of 3.0 in the courses listed under Major in the preceding Summary of Requirements section. In the first route, the student must register for PHYS 29100-PHYS 29200-PHYS 29300 and earn a grade of B or higher based on a bachelor's thesis describing an approved research project completed during the year. The second route to receiving a BA with honors is to pass an approved set of three graduate courses, with a grade of B or higher in each. One such set of courses is PHYS 34100-PHYS 34200 and PHYS 35200; however, other 30000-level courses may be used with approval from the program chair.

### Degree Program in Physics with Specialization in Astrophysics

*With the introduction of the major of Astronomy and Astrophysics in the 2018–19 academic year, the Physics Specialization in Astrophysics is being discontinued. Students who matriculated in Autumn Quarter 2017 or earlier may still complete the specialization with approval from the department. Students entering the College in Autumn Quarter 2018 or later and wish to pursue study in astrophysics should plan to major in Astronomy and Astrophysics.*

The program leading to a BA in physics with a specialization in astrophysics is a variant of the BA in physics. The degree is in physics, with the designation "with specialization in astrophysics" included on the final transcript. Candidates are required to complete all requirements for the BA degree in physics, plus three courses in astrophysics (selected from ASTR 23900 Physics of Galaxies, ASTR 24100 The Physics of Stars, ASTR 24300 Cosmological Physics, ASTR 25400 Radiation Processes in Astrophysics, ASTR 28200 Current Topics in Astrophysics), or two courses in astrophysics plus a senior thesis project in physics (PHYS 29100-29200-29300 Bachelor's Thesis I-II-III) on a topic in astrophysics. If the latter option is chosen, the thesis topic must be approved by the program chair. (This thesis may simultaneously fulfill part of the requirements for honors in physics.) A grade of at least C- must be obtained in each course.

### 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:		100
MATH 15300	Calculus III	
MATH 16300	Honors Calculus III	
PHYS 22000	Introduction to Mathematical Methods in Physics	
Note: students in PHYS 13300 must take PHYS 22000.		
PHYS 15400	Modern Physics	100
PHYS 18500	Intermediate Mechanics	100
PHYS 22100	Mathematical Methods in Physics	100
PHYS 23400	Quantum Mechanics I	100
Two electives, at least one of which is:		200
PHYS 19700	Statistical and Thermal Physics	
PHYS 22500	Intermediate Electricity and Magnetism I	
PHYS 23500	Quantum Mechanics II	
The second elective may be any course that is required by the major or can be used as an elective for the major.		
<b>Total Units</b>		<b>800</b>

The mathematics requirement for the minor is identical to the requirement for the major; please consult the description of the major for more information, particularly regarding PHYS 22000 and PHYS 22100. Note that PHYS 22000 and PHYS 22100 may be replaced by equivalent courses, as approved by the undergraduate program chair. Note also that the PHYS 13300/PHYS 14300, PHYS 22100, and MATH 15300/MATH 16300/PHYS 22000 requirements will be waived for those who must take these courses to satisfy the requirements of a major or another minor. Consequently, the number of courses needed for the minor will vary between five and eight.

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 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 13100-13200-13300 or 15100-15200-15300 or 16100-16200-16300. (MATH 15100-15200-15300 or 16100-16200-16300 may be taken concurrently.)

**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): PHYS 13100 or 14100

**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): PHYS 13200 or 14200

**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): PHYS 13100 or 14100

**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): PHYS 13200 or 14200

**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 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 15400. Modern Physics. 100 Units.**

This course is an introduction to quantum physics. Topics include Einstein's quantum theory of light, the wave nature of particles, atomic structure, the Schrödinger equation, quantum mechanics in one and three dimensions, angular momentum and spin, and the hydrogen atom. Applications to nuclear and solid-state physics are presented. (L)

Instructor(s): Staff Terms Offered: Autumn

Prerequisite(s): PHYS 14300 or (PHYS 13300 and PHYS 22000)

**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: Winter

Prerequisite(s): PHYS 13100 or 14100; PHYS 22100 or MATH 20700 or MATH 20250 (MATH 20250 may be concurrent)

**PHYS 19700. 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. Prerequisite(s): PHYS 23400, and PHYS 22100 or MATH 20500

Instructor(s): Staff Terms Offered: Autumn

Prerequisite(s): PHYS 23400; PHYS 22100 or MATH 20400 or MATH 20800

**PHYS 20900. Fundamentals of Accelerator Physics and Technology. 100 Units.**

The course begins with the historical development of accelerators and their applications. Following a brief review of special relativity, the bulk of the course will focus on acceleration methods and phase stability, basic concepts of magnet design, and transverse linear particle motion. Basic accelerator components such as bending and focusing magnets, electrostatic deflectors, beam diagnostics and radio frequency accelerating structures will be described. The basic concepts of magnet design will be introduced, along with a discussion of particle beam optics. An introduction to resonances, linear coupling, space charge, magnet errors, and synchrotron radiation will also be given. Topics in longitudinal and transverse beam dynamics will be explored, including synchrotron and betatron particle motion. Lastly, a number of additional topics will be reviewed, including synchrotron radiation sources, free electron lasers, high energy colliders, and accelerators for radiation therapy. Several laboratory sessions will provide hands-on experience with hardware and measurement instrumentation.

Terms Offered: Autumn

Prerequisite(s): PHYS 18500 and 22700

**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 23400

**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 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 22000. Introduction to Mathematical Methods in Physics. 100 Units.**

This course, with concurrent enrollment in PHYS 13300, is required of students who plan to major in physics. Topics include infinite series and power series, complex numbers, linear equations and matrices, partial differentiation, multiple integrals, vector analysis, and Fourier series. These methods are used to study Maxwell's equations, wave packets, and coupled oscillators.

Instructor(s): Staff Terms Offered: Spring

Prerequisite(s): PHYS 13200; MATH 15200 or 16200

**PHYS 22100. Mathematical Methods in Physics. 100 Units.**

Topics include linear algebra and vector spaces, ordinary and partial differential equations, calculus of variations, special functions, series solutions of differential equations, and integral transforms.

Instructor(s): Staff Terms Offered: Autumn

Prerequisite(s): PHYS 14300 or (PHYS 13300 and PHYS 22000)

**PHYS 22300. Topics in Mathematical Physics. 100 Units.**

This course will cover topics in mathematical physics selected from the following areas of study: linear algebra; dynamical systems; probability and statistics.

Terms Offered: Winter

Prerequisite(s): PHYS 22100 or MATH 20500 or MATH 20900

**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; PHYS 22100 or MATH 20700 or MATH 20250 (MATH 20250 may be concurrent)

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

Topics include electromagnetic induction, electromagnetic waves, and radiation.

Terms Offered: Spring

Prerequisite(s): PHYS 22500

**PHYS 23400-23500. Quantum Mechanics I-II.**

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

**PHYS 23400. 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: Spring

Prerequisite(s): PHYS 15400; PHYS 22100 or MATH 20250 or MATH 20800

**PHYS 23500. 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: Autumn

Prerequisite(s): PHYS 23400

**PHYS 23500. 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: Autumn

Prerequisite(s): PHYS 23400

**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 23500 and 19700



**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: Spring

Prerequisite(s): PHYS 23500

**PHYS 23800. Modern Atomic Physics. 100 Units.**

This course is an introduction to modern atomic physics. Topics to be covered include atomic structure, fundamental symmetries in atoms, interactions of atoms with radiation, laser spectroscopy, trapping and cooling, Bose-Einstein condensates, and quantum information.

Terms Offered: Autumn

Prerequisite(s): PHYS 23500

**PHYS 24300. Advanced Quantum Mechanics. 100 Units.**

This course will include topics not normally covered in PHYS 23400-23500. Topics may include the following: symmetry in quantum mechanics; quantum mechanics and electromagnetism; adiabatic approximation and Berry phase; path integral formulation; scattering.

Terms Offered: Winter

Prerequisite(s): A grade of B or higher in PHYS 23500 or permission of the instructor

Note(s): PHYS 24300-44300-44400 can be used as a graduate course sequence for Honors.

**PHYS 24500. Relativistic Quantum Mechanics and Introduction to String Theory. 100 Units.**

This course begins with a review of some aspects of classical electrodynamics and non-relativistic quantum mechanics. It will then discuss the new elements that arise when one combines the two, leading to quantum electrodynamics. It will then discuss the incorporation of the other (strong and weak) interactions into the standard model, and describe some of the more recent ideas, such as supersymmetry and string theory.

Terms Offered: Spring

Prerequisite(s): PHYS 22700 and 23500

**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 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 3.0 or higher in courses required for the major is eligible to receive a BA 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 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.





### Font Notice

This document should contain certain fonts with restrictive licenses. For this draft, substitutions were made using less legally restrictive fonts. Specifically:

Times was used instead of Trajan.

Times was used instead of Palatino.

The editor may contact Leepfrog for a draft with the correct fonts in place.