Physics and Astronomy

Undergraduate Study

For the undergraduate curriculum in liberal arts and sciences, major in physics, leading to the degree bachelor of science, see Liberal Arts and Sciences, Curriculum.

Physics and astronomy are basic natural sciences which attempt to describe and provide an understanding of both our world and our universe. Physics serves as the underpinning of many different disciplines including the other natural sciences and technical areas. Graduates are proficient in the methods of rigorous scientific analysis, relevant mathematical techniques, and modern computational and laboratory methods. They have a broad knowledge of physics, including mechanics, electricity and magnetism, thermodynamics, and modern physics. They are able to communicate clearly and effectively at general and technical levels. They are prepared to pursue a wide range of careers as a professional physicist, astronomer, or science educator. They are also prepared to pursue advanced studies and careers in areas as diverse as engineering, medicine, law, and business administration. Many opportunities exist for students who terminate their studies with a bachelor’s degree, especially when combined with technology studies in other areas. Students who meet the necessary scholastic standards often continue their studies in a graduate college, exploring and contributing to new developments in the field.

The department normally expects each student majoring in physics to complete at least the following courses:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 241</td>
<td>Principles and Symmetries in Classical Physics I</td>
<td>5</td>
</tr>
<tr>
<td>PHYS 242</td>
<td>Principles and Symmetries in Classical Physics II</td>
<td>5</td>
</tr>
<tr>
<td>PHYS 321</td>
<td>Introduction to Modern Physics I</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 321L</td>
<td>Introductory Laboratory in Modern Physics I</td>
<td>1</td>
</tr>
<tr>
<td>PHYS 322</td>
<td>Introduction to Modern Physics II</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 322L</td>
<td>Introductory Laboratory in Modern Physics II</td>
<td>1</td>
</tr>
<tr>
<td>PHYS 304</td>
<td>Thermal Physics</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 306</td>
<td>Physics of Wave Motion</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 361</td>
<td>Classical Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 362</td>
<td>Intermediate Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 364</td>
<td>Electricity and Magnetism I</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 365</td>
<td>Electricity and Magnetism II</td>
<td>3</td>
</tr>
<tr>
<td>MATH 317</td>
<td>Theory of Linear Algebra</td>
<td>4</td>
</tr>
<tr>
<td>PHYS 310</td>
<td>Electronic Instrumentation for Experimental Physics</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 311</td>
<td>Intermediate Laboratory</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 311T</td>
<td>Intermediate Laboratory for Secondary Physics Teachers</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 470L</td>
<td>Applied Physics Laboratory</td>
<td>3</td>
</tr>
<tr>
<td>ASTRO 344L</td>
<td>Astronomy Laboratory</td>
<td>3</td>
</tr>
</tbody>
</table>

*PHYS 221 and PHYS 222 may be substituted for PHYS 241 and PHYS 242.

The department offers a minor in astronomy which may be earned by completing 15 credits chosen as follows:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTRO 120</td>
<td>The Sky and the Solar System</td>
<td>3</td>
</tr>
<tr>
<td>ASTRO 150</td>
<td>Stars, Galaxies, and Cosmology</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 470L</td>
<td>Applied Physics Laboratory</td>
<td>3</td>
</tr>
</tbody>
</table>

Other acceptable courses:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 321</td>
<td>Introduction to Modern Physics I</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 361</td>
<td>Classical Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 362</td>
<td>Intermediate Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 364</td>
<td>Electricity and Magnetism I</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 366</td>
<td>Electricity and Magnetism II</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 421</td>
<td>Ultrafast Laser Science and Spectroscopy</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 432</td>
<td>Molecular and Cell Biophysics</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 480</td>
<td>Quantum Mechanics I</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 481</td>
<td>Quantum Mechanics II</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 496</td>
<td>Modern Optics</td>
<td>3</td>
</tr>
</tbody>
</table>

The expected outcomes for students in these programs are:

1. Communication Proficiency requirement: The department requires a grade of C or better in each of ENGL 150 and ENGL 250 (or ENGL 250H), and a C- or better in ENGL 302, ENGL 305, ENGL 309 or ENGL 314. Students are also encouraged to study at least one foreign language.

2. All students are required to earn at least 5 credits in laboratory work in physics. Additional laboratory credits numbered 304 or higher or in approved substitutions.

3. All students must earn at least 56 credits in physics and astronomy courses numbered 304 or higher. The basis of expected courses is not a rigid requirement and changes in this basic list will be approved by the department curriculum committee on recommendation of the student’s adviser when such changes will better serve the student’s needs. In particular, students planning a physics major and also seeking certification for high school teaching may, with the approval of their adviser, follow a significantly different program designed to meet their particular needs; these students should consult the department for further information. Further information concerning programs of study, including sample degree programs, is available from the department.

4. Students majoring in physics who wish an emphasis in astronomy/astrophysics should consider a minor in astronomy (see below). Those planning graduate work in physics or astronomy/astrophysics should add to the basic list the courses PHYS 480 and PHYS 481. Other useful courses include:

<table>
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<tr>
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<tbody>
<tr>
<td>MATH 365</td>
<td>Complex Variables with Applications</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 426</td>
<td>Mathematical Methods for the Physical Sciences</td>
<td>3</td>
</tr>
</tbody>
</table>
1. a broad knowledge of physics, including mechanics, electricity and magnetism, thermodynamics, wave motion and modern physics
2. proficiency in laboratory methods
3. proficiency in modern scientific computational methods
4. a sound foundation in the liberal arts including proficiency in communication skills.

In addition to the performance on exams and course grades, information on evaluating the success in meeting these goals is obtained by:

1. an annual written survey of all students majoring in the program
2. an annual written survey of all graduating seniors
3. a periodic written survey of program alumni
4. student evaluations of all courses
5. adviser evaluations
6. a bimonthly meeting of program majors with the department chair

Graduate Study

The department offers studies for the degrees master of science and doctor of philosophy with majors at both levels in applied physics, astrophysics, condensed matter physics, high energy physics, nuclear physics, and physics; and minor credit courses for students majoring in other departments.

Facilities of various research groups of the department, the Ames Laboratory, and the Applied Science Center, including the Microelectronics Research Center, are available for research.

Students with bachelor’s degrees in physics or astronomy from other institutions ordinarily will qualify for graduate study at Iowa State provided they have satisfied the requirements for the bachelor’s degree and that the work is satisfactory. They are able to communicate effectively to a wide range of audiences, from the general public to research colleagues. Their skills in rigorous scientific thinking prepare them for leadership in the broader community. They are skilled in carrying out research, communicating research results, and soliciting research support. They have considerable teaching experience. They have developed problem solving skills that prepare them for careers in either industry or academia.

All candidates for an advanced degree in physics are expected to complete:

<table>
<thead>
<tr>
<th>Course</th>
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</thead>
<tbody>
<tr>
<td>PHYS 531</td>
<td>Statistical Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 564</td>
<td>Advanced Classical Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 571</td>
<td>Electricity and Magnetism I</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 572</td>
<td>Electricity and Magnetism II</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 591</td>
<td>Quantum Physics I</td>
<td>4</td>
</tr>
<tr>
<td>PHYS 592</td>
<td>Quantum Physics II</td>
<td>4</td>
</tr>
</tbody>
</table>

Candidates for an advanced degree in applied physics are expected to complete:

<table>
<thead>
<tr>
<th>Course</th>
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<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 571</td>
<td>Electricity and Magnetism I</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 591</td>
<td>Quantum Physics I</td>
<td>4</td>
</tr>
<tr>
<td>PHYS 470L</td>
<td>Applied Physics Laboratory</td>
<td>2-5</td>
</tr>
<tr>
<td>PHYS 699</td>
<td>Research</td>
<td>arr</td>
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</tbody>
</table>

† Arranged with instructor.

 Candidates for an advanced degree in astrophysics should complete:

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<td>3</td>
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<td>PHYS 564</td>
<td>Advanced Classical Mechanics</td>
<td>3</td>
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<td>PHYS 571</td>
<td>Electricity and Magnetism I</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 591</td>
<td>Quantum Physics I</td>
<td>4</td>
</tr>
<tr>
<td>ASTRO 505</td>
<td>Astrophysical Processes</td>
<td>3</td>
</tr>
<tr>
<td>ASTRO 510</td>
<td>Observational Astrophysics</td>
<td>3</td>
</tr>
</tbody>
</table>

Astrophysics Ph.D. candidates must take at least three of the 580 level Astro courses, while candidates for the Research Masters must take at least two 580 level Astro courses.

Except for the applied physics major where a thesis is always required, the degree master of science is offered both with and without thesis. For all areas of study except applied physics the basic requirements for the M.S. are the same: at least 30 credits of acceptable graduate work must be completed, not less than 21 of which must be in physics or astronomy. Students must complete not less than 6 credits from outside their major area, with 3 credits being required from outside the department, and 3 credits from a 500 or 600 level course in another area of specialization. Students choosing a M.S. degree with thesis may apply up to 8 credits of 699 but no credits of 599 toward the minimum 30 credits. Students choosing a degree without thesis should apply 2 credits of 599, but may not apply any credits of 699 toward the minimum 30 credits.

Students whose major area is applied physics must complete at least 30 credits of acceptable graduate work for the M.S. degree and not less than 19 credits of these must be in the required courses listed above; the remaining 11 credits of the 30 credit minimum may be chosen freely either from within the student’s major area or from without and either from the department or outside, but it should be noted that not more than 3 credits of PHYS 699 Research may be applied toward the 30 credit minimum.

In addition to course work in the major area of study, all candidates for the Ph.D. degree must complete 12 credits from outside this area. Of these 6 must be taken from other departments and 6 must be taken from the department with the additional constraint that this latter 6 must include at least one 500 or 600 level introductory course in another area of specialization. Each candidate for the Ph.D. degree is required to teach one year of elementary physics or astronomy.

Graduate students interested in a physics minor should contact the department for requirements.

Courses primarily for undergraduates:

ASTRO 102. North Star Astronomy.
Cr. 1. F.S.
An entirely web-based course covering topics in observing the sky and navigation by the stars for students with little or no previous experience. The course combines material on common naked-eye phenomena, such as daily and seasonal variations in the sky, with information on how these helped navigators determine where they are on Earth. The course “lectures” are on-line, interactive units with build in exercises, hands-on (offline) activities and layers of help. Graded homework and quizzes are administered via Web-CT. Students who take Astro 120 may count credit in only one of Astro 102 or 103 toward graduation.

ASTRO 103. Evening Star.
Cr. 1. F.S.
An entirely web-based course covering topics in celestial mechanics (“Rocket science”) for students with little or no previous experience. It combines the geography of the solar system with discussion of methods of traveling to the other planets. The course “lectures” are on-line, interactive units with built-in exercises, hands-on (offline) activities, and layers of help. Graded homework and quizzes are administered via WebCT. Students who take Astro 120 may count credit in only one of Astro 102 or 103 toward graduation.

ASTRO 106. Earth and Space Science for Elementary Education Majors.
(Cross-listed with GEOL). (2-0) Cr. 2. F.S. Prereq: Major in elementary or early childhood education.
Fundamental concepts of Earth and Space Science, including the solar system, weather and climate, water and soils, plate tectonics, and geologic hazards. Online course format.

ASTRO 106L. Earth and Space Science for Elementary Education Majors: Laboratory.
(Cross-listed with GEOL). (0-2) Cr. 1. F.S. Prereq: Restricted to elementary and early childhood education majors; to be taken concurrently with GEOL 106/ASTRO 106 Inquiry-based lab exploring fundamental concepts of Earth and Space Science, including the solar system, weather and climate, water and soils, plate tectonics, and geologic hazards. Must be taken concurrently with GEOL/ASTRO 106.

ASTRO 120. The Sky and the Solar System.
(3-0) Cr. 3. F.S.SS.
For the nonscientist. The sky: constellations; motions of the sun, moon, and planets; seasons and the calendar; eclipses. The solar system: origin and evolution; characteristics of the sun, planets, satellites, comets, meteorites, and asteroids. Extensive use of the planetarium is included. Students who take Astro 120 may count credit in only one of Astro 102 or 103 toward graduation.
ASTRO 125L. The Sky and the Solar System Laboratory. 
(0-2) Cr. 1. F.S. Prereq: Concurrent or previous enrollment in ASTRO 120 
Laboratory course to accompany Astro 120. Students carry out practical exercises 
involving naked eye and telescopic observing to explore and reinforce ideas 
covered in Astro 120. Activities based on a sky-simulation computer program 
and other weather-independent exercises are also included.

ASTRO 150. Stars, Galaxies, and Cosmology. 
(3-0) Cr. 3. F.S. 
For the nonscientist. Observational aspects of stellar astronomy: motions, 
distances, sizes, spectra; types of stars; variability; binary systems. Stellar 
evolution: the birth, life, and death of stars, including supernovae, neutron stars, 
and black holes. The Milky Way Galaxy: clouds of matter in space, the structure 
and evolution of our galaxy. Other galaxies, clusters of galaxies, quasars. 
Theories of the origin of the universe.

ASTRO 250. Astronomy Bizarre. 
(3-0) Cr. 3. S. Prereq: ASTRO 120 or ASTRO 150 
For the nonscientist. New and exciting topics in modern astronomy. Galaxy 
and star formation. Black holes and pulsars. Colliding galaxies. Quasars. 
Cosmology, the Big Bang and the future of the universe. Prospects and searches 
for extraterrestrial life.

ASTRO 290. Independent Study. 
Cr. 1-4. Repeatable. Prereq: Permission of instructor

ASTRO 342. Introduction to Solar System Astronomy. 
(3-0) Cr. F. Prereq: PHYS 222 
Analytical and comparative studies of solar system objects-planets, satellites, 
rings, asteroids, comets, meteoroids, and interplanetary dust— with emphasis on 
the physical processes affecting them, their interactions, and their evolution. 
Orbital mechanics, including perturbations, stability, and resonances. Tidal forces 
and effects. Radiation laws and thermal physics with applications. Brief study of 
the sun as a star, and of stellar evolution. Origin and evolution of the solar system. 
Detection of other planetary systems. Nonmajor graduate credit.

ASTRO 344L. Astronomy Laboratory. 
(1-6) Cr. 3. F. Prereq: PHYS 222 
Experiments in optical astronomy. Observational techniques, ranging from stellar 
photometry to CCD imaging. Available instruments include a variety of small 
telescopes up to 14-inch in size. Class meets at Fick Observatory south of Boone. 
Nonmajor graduate credit.

ASTRO 346. Introduction to Astrophysics. 
(3-0) Cr. 3. S. Prereq: PHYS 222 
Basic radiation theory; spectra. Observational determination of stellar properties; 
spectral classification. Binary systems. Stellar structure and evolution. White 
dwarfs, neutron stars, black holes. The Galaxy: structure and composition; 
the interstellar medium. Other galaxies; active galaxies; cosmology. Nonmajor graduate credit.

(Dual-listed with ASTRO 505). (3-0) Cr. 3. F. Prereq: ASTRO 346 or permission of instructor 
Survey of astrophysical processes relating to stars, galaxies and the Universe. 
Radiation transport, radiation processes, scattering, kinetic description of plasma, 
hydrodynamics, magnetohydrodynamics, MHD waves, shocks, properties of 
systems in local thermodynamic equilibrium, non-thermal systems, astrophysical 
effects of general relativity.

ASTRO 450. Undergraduate Research. 
Cr. 1-6. Repeatable. F.S.SS. Prereq: Permission of instructor 
Research under supervision of astronomy faculty.

ASTRO 450L. Undergraduate Research. 
Cr. 1-6. Repeatable. F.S.SS. Prereq: ASTRO 344L and permission of instructor 
Laboratory or observational project under supervision of astronomy faculty.

ASTRO 490. Independent Study. 
Cr. 1-4. Repeatable, maximum of 9 credits. Prereq: 6 credits in astronomy, 
permission of instructor 
No more than 9 credits of Astro 490 may be counted toward graduation.

ASTRO 490H. Independent Study: Honors. 
Cr. 1-4. Repeatable, maximum of 9 credits. Prereq: 6 credits in astronomy, 
permission of instructor 
No more than 9 credits of Astro 490 may be counted toward graduation.

Courses primarily for graduate students, open to qualified undergraduates:

(Dual-listed with ASTRO 405). (3-0) Cr. 3. F. Prereq: ASTRO 346 or permission of instructor 
Survey of astrophysical processes relating to stars, galaxies and the Universe. 
Radiation transport, radiation processes, scattering, kinetic description of plasma, 
hydrodynamics, magnetohydrodynamics, MHD waves, shocks, properties of 
systems in local thermodynamic equilibrium, non-thermal systems, astrophysical 
effects of general relativity.

ASTRO 510. Observational Astrophysics. 
(2-3) Cr. 3. Alt. F., offered 2011. Prereq: ASTRO 405 or ASTRO 505 
Techniques in optical and near-IR astronomy, including spectroscopy and CCD 
photometry. Emphasis on projects involving proficiency in the use of research 
telescopes and modern instrumentation. Project topics range from photometric 
studies of pulsating and binary star systems to deep CCD imaging of faint nebulae 
and galaxies.

ASTRO 580. Stellar Astrophysics. 
(3-0) Cr. 3. Alt. S., offered 2013. Prereq: ASTRO 405 or ASTRO 505 
The interior structure and atmospheric properties of stars: Stellar structure 
equations and constitutive relations: energy generation, energy transport by 
radiation and convection; equation of state, nuclear energy generation and 
nucleosynthesis. Numerical and analytic solutions to the equations of structure 
and evolution. Observational connections through the theory of radiative transfer. 
Line and continuum processes and sources of opacity. Non-LTE and statistical 
equilibrium. Line profiles. Interpretation of stellar spectra: temperature, pressure, 
and abundance determinations. Stellar evolution from formation to final phases.

ASTRO 582. High Energy Astrophysics. 
(3-0) Cr. 3. Alt. F., offered 2012. Prereq: ASTRO 405 or ASTRO 505 
Interactions of high-energy particles, non-thermal radiation processes, spectral 
evolution of non-thermal systems, cosmic rays, active galactic nuclei, pulsars, 
neutrinos, measurement techniques for relativistic charged particles, high energy 
photons, and neutrinos.

ASTRO 584. Galactic Astronomy. 
(3-0) Cr. 3. Alt. S., offered 2012. Prereq: ASTRO 405 or ASTRO 505 
Overall structure of our Galaxy and the interstellar medium. Physical processes in 
the interstellar medium (e.g., heating and cooling mechanisms, turbulence). 
Observational techniques for studying the interstellar medium. Kinematics and 
chemical evolution of the Galaxy.

ASTRO 586. Extragalactic Astronomy. 
(3-0) Cr. 3. Alt. F., offered 2011. Prereq: ASTRO 405 or ASTRO 505 
Galaxy evolution, dynamics of external galaxies, evolution and classification of 
galaxies, groups and clusters of galaxies, extragalactic radio sources, quasars, 
structure formation, cosmological models and their observational consequences.

ASTRO 590. Special topics. 
Cr. arr. Repeatable.

ASTRO 599. Creative Component. 
Cr. arr. Prereq: Permission of instructor 
Individually directed study of research-level problems for students electing the 
nonthesis M.S. option in astronomy.

Courses for graduate students: 
ASTRO 650. Advanced Seminar. 
(1-0) Cr. 1. Repeatable. F.S. 
Topics of current interest in astronomy and astrophysics. Offered on a 
satisfactory-fail basis only.

ASTRO 660. Advanced Topics in Astronomy and Astrophysics. 
Cr. 1-3. Repeatable. F.S. 
Topics in stellar, galactic, and extragalactic astronomy, including stellar evolution, 
solar physics, variable stars, compact objects, the interstellar medium, active 
galaxies and quasars, formation and evolution of galaxies, cosmology, high 
energy astrophysics, advanced observational techniques, and astrophysical 
applications of hydrodynamics.

ASTRO 675. Advanced Stellar Astrophysics. 
(3-0) Cr. 3. Alt. S., offered 2012. Prereq: ASTRO 405 or ASTRO 505; and ASTRO 580 
Advanced topics in stellar astrophysics. Dynamic and extended atmospheres, 
chromospheres, coronae, and stellar winds. MHD, stellar activity, and dynamo 
theory. Radiative transfer and the transition from extended atmospheres to the 
terrestrial medium. Diffusive processes in stellar atmospheres and interiors. 
Techniques for quantitative analysis of planetary and stellar spectra including 
detailed modeling and spectrum synthesis. Evolution in interacting binaries. 
Nucleosynthesis II. Variable stars. Supernovae. Neutron stars and black holes.
PHYS 311. Intermediate Laboratory.  
Cr. 1-2. Repeatable. S. Prereq: PHYS 322  
Experiments in classical and modern physics performed independently by each student. Nonmajor graduate credit.

PHYS 311T. Intermediate Laboratory for Secondary Physics Teachers.  
(0-6) Cr. 3. Repeatable. S. Prereq: PHYS 112 or PHYS 222  
Experiments in classical and modern physics performed independently by each student. For students preparing for a career in high school teaching.

PHYS 321. Introduction to Modern Physics I.  
(3-0) Cr. 3. F. Prereq: PHYS 222, credit or enrollment in MATH 266  
Quantum nature of matter: photons, de Broglie’s postulate: wave-like properties of matter; Bohr’s model of hydrogen atom; Schrodinger equations in one dimension: energy quantization; detailed solutions for potential steps, barriers and wells; one-electron atoms, spin and magnetic interactions; ground states, optical and x-ray excitations of multi-electron atoms.

PHYS 321L. Introductory Laboratory in Modern Physics I.  
(0-2) Cr. 1. F. Prereq: Credit or enrollment in PHYS 321  

PHYS 322. Introduction to Modern Physics II.  
(3-0) Cr. 3. S. Prereq: PHYS 321  
Quantum statistics; lasers; physics of molecules. Properties of solids, including electron band structure, superconductivity and magnetism. Nuclear physics, including nuclear sizes and masses, stability, decay modes, reactions, fission and fusion. Elementary particles, including strangeness, charm, and quarks. Fundamental forces of nature.

PHYS 322L. Introductory Laboratory in Modern Physics II.  
(0-2) Cr. 1. S. Prereq: Credit or enrollment in PHYS 322  
Experiments related to the foundations of modern physics. Radioactive decay, elementary particles, Hall effect, quantization, spectroscopy, statistics and instrumentation.

(3-0) Cr. 3. F. Prereq: PHYS 222, MATH 265, MATH 266  
Newtonian mechanics including forced oscillations, central forces and orbital motion, collisions, moving frames of reference, Lagrange’s equations. Nonmajor graduate credit.

(3-0) Cr. 3. S. Prereq: PHYS 361  
Rigid body motion; small oscillations, normal modes. Special relativity including length contraction, time dilation, simultaneity, Lorentz transformation, 4-vector covariant formalism, relativistic mechanics. Nonmajor graduate credit.

PHYS 364. Electricity and Magnetism I.  
(3-0) Cr. 3. F. Prereq: PHYS 222  
Static electric and magnetic fields, potential theory; electromagnetism, Maxwell’s equations. Nonmajor graduate credit.

PHYS 365. Electricity and Magnetism II.  
(3-0) Cr. 3. S. Prereq: PHYS 364  
Relativistic electromagnetic theory; radiation and propagation of electromagnetic waves; interaction with matter. Nonmajor graduate credit.

Cr. R. S.  
Recommended for all junior physics majors. Career opportunities: graduate school programs and application, job placement, alternative careers, basic skills needed for the job market competition. Offered on a satisfactory-fail basis only.

PHYS 398. Cooperative Education.  
Cr. R. F.S.S. Prereq: Permission of the department cooperative education coordinator; junior classification  
Required of all cooperative education students. Students must register for this course prior to commencing each work period.

Cr. 1-2. Repeatable, maximum of 2 credits. F. Prereq: Permission of instructor  
Review of materials and curricula for secondary school physics presented and discussed by members of the class. Required for approval to teach physics in secondary schools.

(Dual-listed with PHYS 521). (3-0) Cr. 3. F. Prereq: PHYS 321, PHYS 365, or equivalent with permission of instructor  
Introduction to ultrafast lasers, nonlinear optics, and their applications. Topics selected from: basic optics, atom-photon interactions, electrodynamics of condensed matter, laser physics, ultrafast and nonlinear optics, ultrashort pulse generation, broadband pulse generation, time-resolved spectroscopy and instrumentation. Nonmajor graduate credit.

(3-0) Cr. 3. F. Prereq: Math 266 or 267  

PHYS 432. Molecular and Cell Biophysics.  
(Dual-listed with PHYS 532). (3-0) Cr. 3. S. Prereq: PHYS 304 or CHEM 325  
Quantitative description of biological systems using basic physical laws, including a brief discussion of a variety of biophysical techniques. Topics include: thermodynamics, chemical equilibrium, gene expression, structure and physical properties of nucleic acids and proteins, folding of nucleic acids and proteins, chemical kinetics, catalysis, allosteric enzymes, cell membrane structure and physical properties, and machines in cell membranes. Nonmajor graduate credit.

PHYS 450. Undergraduate Research.  
Cr. 1-6. Repeatable. F.S.SS. Prereq: Permission of instructor  
Theoretical research under supervision of physics faculty.

PHYS 450L. Undergraduate Research.  
Cr. 1-6. Repeatable. F.S.SS. Prereq: PHYS 311, permission of instructor  
Laboratory project under supervision of physics faculty.

PHYS 461. Physics of Biomolecules.  
(Dual-listed with PHYS 561). (3-0) Cr. 3. F. Prereq: PHYS 304 or CHEM 325, BBMB 301, or permission of instructor  
Cell and Molecular Biophysics. Physical techniques used to characterize the structure, dynamics and properties of biomolecules with emphasis on single molecule techniques.

PHYS 470L. Applied Physics Laboratory.  
Cr. 2-5. Repeatable. F.S.SS. Prereq: PHYS 322 and permission of instructor  
Studies in modern experimental techniques via experimentation and simulation in various areas of applied physics, e.g. superconductivity, optical spectroscopy, nuclear magnetic resonance, electron spin resonance, x-ray diffraction, and computation of electronic and structural properties of matter.

PHYS 480. Quantum Mechanics I.  
(3-0) Cr. 3. F. Prereq: PHYS 222, MATH 385  
First semester of a full-year course. A systematic development of the formalism and applications of quantum mechanics. Solutions to the time independent Schrodinger equation for various one-dimensional potentials including the harmonic oscillator; operator methods; Heisenberg picture; angular momentum; the hydrogen atom; spin; symmetry properties. Nonmajor graduate credit.

PHYS 481. Quantum Mechanics II.  
(3-0) Cr. 3. S. Prereq: PHYS 480  
Continuation of 480. Addition of angular momentum; charged particles in electromagnetic fields; time-independent perturbation theory; variational principles; WKB approximation; interaction picture; time-dependent perturbation theory; adiabatic approximation; scattering; selected topics in radiation theory; quantum paradoxes. Nonmajor graduate credit.

PHYS 490. Independent Study.  
Cr. 1-4. Repeatable, maximum of 9 credits. Prereq: 6 credits in physics, permission of instructor  
No more than 9 credits of Phys 490 may be counted toward graduation.

PHYS 490H. Independent Study, Honors.  
Cr. 1-4. Repeatable, maximum of 9 credits. Prereq: 6 credits in physics, permission of instructor  
No more than 9 credits of Phys 490 may be counted toward graduation.
PHYS 496. Modern Optics. (Cross-listed with E E). (3-0) Cr. 3. S. Prereq: Credit or enrollment in PHYS 322, PHYS 365, and PHYS 480
Review of wave and electromagnetic theory; topics selected from: reflection/ refraction, interference, geometrical optics, Fourier analysis, dispersion, coherence, Fraunhofer and Fresnel diffraction, holography, quantum optics, nonlinear optics. Nonmajor graduate credit.

PHYS 498. Cooperative Education. Cr. R. F.S.S. Prereq: Permission of the department cooperative education coordinator; senior classification
Required of all cooperative education students. Students must register for this course prior to commencing each work period.

Courses primarily for graduate students, open to qualified undergraduates:

PHYS 501. Oral Communication of Physics Seminar. (2-0) Cr. 1. Repeatable. F.
A practical introduction to communication methods in physics and astronomy classrooms and professional settings. For graduate physics majors only. Offered on a satisfactory-fail basis only.

(1-1) Discussion by research staff of their research areas, expected thesis research work, and opportunities in the field. For graduate physics majors only. Offered on a satisfactory-fail basis only.

PHYS 511. Condensed Matter Physics I. (3-0) Cr. 3. S. Prereq: PHYS 304, credit or enrollment in PHYS 481
First semester of a full-year course. Free electron model; crystal symmetry; band theory of solids; transport properties; Fermi surface; phonons; semiconductors; crystal surfaces; magnetism; superconductivity.

PHYS 512. Condensed Matter Physics II. (3-0) Cr. 3. F. Prereq: PHYS 511
Continuation of 511. Free electron model; crystal symmetry; band theory of solids; transport properties; Fermi surface; phonons; semiconductors; crystal surfaces; magnetism; superconductivity.

PHYS 521. Ultrafast Laser Science and Spectroscopy. (Dual-listed with PHYS 421). Cr. 3. F. Prereq: PHYS 321, PHYS 365, or equivalent with permission of instructor
Introduction to ultrafast lasers, nonlinear optics, and their applications. Topics selected from: basic optics, atom-photon interactions, electrodynamics of condensed matter, laser physics, ultrafast and nonlinear optics, ultrashort pulse generation, broadband pulse generation, time-resolved spectroscopy and instrumentation.

PHYS 526. Particle and Nuclear Physics. (4-0) Cr. 4. S. Prereq: Credit or enrollment in PHYS 481
Basic properties and structures of nuclei, hadrons, and elementary particles; weak and strong interactions; the Standard Model; accelerators and detectors; nuclear models; nuclear decay and stability; nuclear astrophysics; the Higgs mechanism; the CKM matrix; running coupling constants; relativistic heavy-ion collisions; selected topics beyond the standard model such as SUSY and grand unification.

PHYS 531. Statistical Mechanics. (3-0) Cr. 3. S. Prereq: PHYS 304 and credit or enrollment in PHYS 481, MATH 465, credit or enrollment in MATH 365 or MATH 426
Thermodynamic properties of systems of many particles obeying Boltzmann, Fermi-Dirac, and Bose-Einstein statistics; microcanonical, canonical, and grand canonical ensembles and their application to physical problems; density matrices; introduction to phase transitions; renormalization group theory; kinetic theory and fluctuations.

PHYS 532. Molecular and Cell Biophysics. (Dual-listed with PHYS 432). (3-0) Cr. 3. S. Prereq: PHYS 304 or CHEM 325
Quantitative description of biological systems using basic physical laws, including a brief discussion of a variety of biophysical techniques. Topics include: thermodynamics, chemical equilibrium, gene expression, structure and physical properties of nucleic acids and proteins, folding of nucleic acids and proteins, chemical kinetics, catalysis, allosteric enzymes, cell membrane structure and physical properties, and machines in cell membranes.

PHYS 534. Symmetry and Group Theory in Physics. (3-0) Cr. 3. S. Prereq: Credit or enrollment in PHYS 481
Theory of groups and group representations; introduction to both point and continuous groups, and their applications in physics.

PHYS 535. Physics of Semiconductors. (Cross-listed with E E). (3-3) Cr. 4. Prereq: E E 311 and E E 332
Basic elements of quantum theory. Fermi statistics, motion of electrons in periodic structures, crystal structure, energy bands, equilibrium carrier concentration and doping, excess carriers and recombination, carrier transport at low and high fields, space charge limited current, photo-conductivity in solids, phonons, optical properties, amorphous semiconductors, heterostructures, and surface effects. Laboratory experiments on optical properties, carrier lifetimes, mobility, defect density, doping density, photo-conductivity, diffusion length of carriers.

PHYS 536. Physics of Semiconductor Devices. (Cross-listed with E E). (3-0) Cr. 3. Prereq: E E 535
P-n junctions, band-bending theory, tunneling phenomena, Schottky barriers, heterojunctions, bipolar transistors, field-effect transistors, negative-resistance devices and optoelectronic devices.

PHYS 541. General Relativity. (3-0) Cr. 3. F. Prereq: PHYS 362, MATH 307 or MATH 317
Tensor analysis and differential geometry developed and used to formulate Einstein field equations. Schwarzschild and Kerr solutions. Other advanced topics may include gravitational radiation, particle production by gravitational fields, alternate gravitational theories, attempts at unified field theories, cosmology.

PHYS 551. Computational Physics. (0-4) Cr. 2. S. Prereq: PHYS 365, credit or enrollment in PHYS 481
Use of modern computational techniques to analyze topics in classical and modern physics. Offered on a satisfactory-fail basis only.

PHYS 561. Physics of Biomolecules. (Dual-listed with PHYS 461). (3-0) Cr. 3. F. Prereq: PHYS 304 or CHEM 325, BBMB 301, or permission of instructor; graduate student classification in Science/ Engineering
Cell and Molecular Biophysics. Physical techniques used to characterize the structure, dynamics and properties of biomolecules with emphasis on single molecule techniques.

PHYS 564. Advanced Classical Mechanics. (3-0) Cr. 3. S. Prereq: PHYS 362, MATH 426, MATH 465
Variational principles, Lagrange’s equations, Hamilton’s canonical equations, canonical transformations, Hamilton-Jacobi theory, infinitesimal transformations, classical field theory, canonical perturbation theory, classical chaos.

PHYS 571. Electricity and Magnetism I. (3-0) Cr. 3. F. Prereq: PHYS 365, MATH 426
Electrostatics, magnetostatics, boundary value problems, Maxwell’s equations, wave phenomena in macroscopic media, wave guides.

PHYS 572. Electricity and Magnetism II. (3-0) Cr. 3. S. Prereq: PHYS 571
Special theory of relativity, least action and motion of charged particles in electromagnetic fields, radiation, collisions between charged particles, multipole fields, radiation damping.

PHYS 590. Special Topics. Cr. arr. Repeatable. Prereq: Permission of instructor
Topics of current interest.

PHYS 590A. Nuclear Physics. Cr. arr. Repeatable. Prereq: Permission of instructor
Topics of current interest.

PHYS 590B. Condensed Matter Physics. Cr. arr. Repeatable. Prereq: Permission of instructor
Topics of current interest.

PHYS 590C. High Energy Physics. Cr. arr. Repeatable. Prereq: Permission of instructor
Topics of current interest.

PHYS 590D. Physics. Cr. arr. Repeatable. Prereq: Permission of instructor
Topics of current interest.

PHYS 590E. Applied Physics. Cr. arr. Repeatable. Prereq: Permission of instructor
Topics of current interest.

PHYS 590F. Biophysics. Cr. arr. Repeatable. Prereq: Permission of instructor
Topics of current interest.
PHYS 591. Quantum Physics I.  
(4-0) Cr. 4. F. Prereq: PHYS 481  
First semester of a full-year course. Postulates of quantum mechanics; time-dependent and time-independent Schrödinger equations for one-, two-, and three-dimensional systems; theory of angular momentum; Rayleigh-Schrödinger time-independent perturbation theory.

PHYS 592. Quantum Physics II.  
(4-0) Cr. 4. S. Prereq: PHYS 591  
Continuation of 591. Variational theorem and WKB method; time-dependent perturbation theory and 2nd quantization of the EM field in Coulomb gauge; method of partial waves and Born approximation for scattering by central potentials; identical particles and symmetry; Dirac and Klein-Gordon equation for free particles; path integral formalism.

PHYS 599. Creative Component.  
Cr. arr. Prereq: Permission of instructor  
Individually directed study of research-level problems for students electing the nonthesis M.S. degree option.

Courses for graduate students:

PHYS 611. Quantum Theory of Condensed Matter.  
(3-0) Cr. 3. S. Prereq: PHYS 512 and PHYS 681 or permission of instructor.  
Quasiparticles in condensed matter: phonons, magnons, photons, electrons. Quantum theory of interacting many body systems: Green’s functions and diagrammatic techniques.

PHYS 624. Advanced Nuclear Physics.  
(3-0) Cr. 3. Prereq: PHYS 526 and PHYS 592  
Microscopic few-body and many-body theory; theory of effective Hamiltonians; relativistic nuclear physics; nuclear effects in hadron-nucleus, lepton-nucleus, and nucleus-nucleus reactions.

PHYS 625. Physics of Strong Interactions.  
(3-0) Cr. 3. Prereq: PHYS 681  
Quark model; Quantum Chromodynamics (QCD); perturbation methods for QCD; effective field theories for pions and nucleons; finite temperature field theories; quark-gluon plasma; phase transitions in QCD.

PHYS 637. Elementary Particle Physics I.  
(3-0) Cr. 3. Prereq: PHYS 526 and PHYS 592  
First semester of a full year course. Properties of leptons, bosons, and quarks and their interactions; quantum chromodynamics, Glashow-Weinberg-Salam model, grand unification theories, supersymmetry; modern theoretical techniques and tests of the Standard Model.

PHYS 638. Elementary Particle Physics II.  
(3-0) Cr. 3. Prereq: PHYS 637  
Continuation of 637. Properties of leptons, bosons, and quarks and their interactions; quantum chromodynamics, Glashow-Weinberg-Salam model, grand unification theories, supersymmetry, and superstring theory; modern theoretical techniques.

(Cross-listed with MATH). (3-0) Cr. 3. S.  
Modeling of the dynamics of complex systems on multiple scales: Classical and dissipative molecular dynamics, stochastic modeling and Monte-Carlo simulation; coarse grained nonlinear dynamics, interface propagation and spatial pattern formation.

PHYS 650. Advanced Seminar.  
(1-0) Cr. 1. Repeatable. F.S.  
Topics of current interest. Offered on a satisfactory-fail basis only.

PHYS 650A. Nuclear Physics.  
(1-0) Cr. 1. Repeatable. F.S.  
Topics of current interest. Offered on a satisfactory-fail basis only.

PHYS 650B. Condensed Matter Physics.  
(1-0) Cr. 1. Repeatable. F.S.  
Topics of current interest. Offered on a satisfactory-fail basis only.

PHYS 650C. High Energy Physics.  
(1-0) Cr. 1. Repeatable. F.S.  
Topics of current interest. Offered on a satisfactory-fail basis only.

PHYS 650D. Physics.  
(1-0) Cr. 1. Repeatable. F.S.  
Topics of current interest. Offered on a satisfactory-fail basis only.

PHYS 650E. Applied Physics.  
(1-0) Cr. 1. Repeatable. F.S.  
Topics of current interest. Offered on a satisfactory-fail basis only.