PHYSICS, BACHELOR OF SCIENCE (B.S.) WITH A CONCENTRATION IN NANOSCIENCE

The Bachelor of Science in Physics with a concentration in nanoscience requires a minimum of 120 credits. The curriculum prepares students for careers in industry, academia, applied health or nanoscience-related areas. The curriculum also prepares students for graduate studies in nanoscience and related areas.

Student learning outcomes

Upon completing this program, students will know how to do the following:

Physics core outcomes

• Perform scientific reasoning and complex problem-solving
  Physics majors will receive a fundamental understanding of the main areas of physics so that they are prepared for jobs that use physics-based technologies. They are expected to have mastered the analytical approach to solving technical problems by identifying simple subsystems that obey known physical laws and using these laws to approximate the behavior of the whole system.

• Demonstrate a fundamental understanding of the main areas of physics

• Demonstrate communication skills, both written and oral, needed to explain the analysis of technical problems

• Demonstrate scientific literacy skills including searching, reading and critically reviewing scientific publications

• Demonstrate proficiency in information processing by generating and interpreting data presented in tables, graphs, drawings and models

Nanoscience concentration-specific outcome

• Demonstrate a fundamental understanding of the novel phenomena of matter that occur at the size scale of nanometers

Double major in engineering and physics

A detailed description of this program (http://bulletin.vcu.edu/undergraduate/engineering/double-major-physics/) can be found in the “College of Engineering” section of this bulletin.

Students must complete 40-42 credits in physics and physics-related electives and 26-34 credits in ancillary requirements.

Degree requirements for Physics, Bachelor of Science (B.S.) with a concentration in nanoscience

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 208</td>
<td>University Physics II</td>
<td>5</td>
</tr>
<tr>
<td>PHYS 301</td>
<td>Classical Mechanics I</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 320</td>
<td>Modern Physics and Modern Physics Laboratory</td>
<td>4</td>
</tr>
<tr>
<td>PHYS 340</td>
<td>Statistical Mechanics and Thermodynamics</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 376</td>
<td>Electromagnetism I</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 380</td>
<td>Quantum Physics I</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 450</td>
<td>Senior Physics Laboratory</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 490</td>
<td>Seminar in Conceptual Physics</td>
<td>1</td>
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</table>

• Concentration requirements

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
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</thead>
<tbody>
<tr>
<td>PHYS 335</td>
<td>Experimental Skills for Physicists</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 470</td>
<td>Introduction to Nanoscience</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 492</td>
<td>Independent Study with NANO faculty</td>
<td>3</td>
</tr>
</tbody>
</table>

Concentration electives

Select two from:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEM 102 &amp; CHEZ 102</td>
<td>General Chemistry II and General Chemistry Laboratory II (four credits)</td>
<td></td>
</tr>
<tr>
<td>EGRE 334</td>
<td>Introduction to Microfabrication (four credits)</td>
<td></td>
</tr>
<tr>
<td>NANO 570</td>
<td>Nanoscale Physics (three credits)</td>
<td></td>
</tr>
<tr>
<td>PHYS 377</td>
<td>Electromagnetism II (three credits)</td>
<td></td>
</tr>
<tr>
<td>PHYS 522</td>
<td>Optics and Laser Physics (three credits)</td>
<td></td>
</tr>
<tr>
<td>PHYS 560</td>
<td>Fundamentals of Semiconductor Nanostructures (three credits)</td>
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Ancillary requirements

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<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
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</thead>
<tbody>
<tr>
<td>CHEM 101</td>
<td>General Chemistry I (satisfies general education AOI for scientific and logical reasoning)</td>
<td>3</td>
</tr>
<tr>
<td>CHEZ 101</td>
<td>General Chemistry Laboratory I</td>
<td>1</td>
</tr>
<tr>
<td>HUMS 202</td>
<td>Choices in a Consumer Society</td>
<td>1</td>
</tr>
<tr>
<td>MATH 200</td>
<td>Calculus with Analytic Geometry I (satisfies general education quantitative foundations)</td>
<td>4</td>
</tr>
<tr>
<td>MATH 201</td>
<td>Calculus with Analytic Geometry II</td>
<td>4</td>
</tr>
<tr>
<td>MATH 301</td>
<td>Differential Equations</td>
<td>3</td>
</tr>
<tr>
<td>MATH 307</td>
<td>Multivariate Calculus</td>
<td>4</td>
</tr>
<tr>
<td>PHYS 207</td>
<td>University Physics I (satisfies general education BOK for natural sciences and AOI for scientific and logical reasoning)</td>
<td>5</td>
</tr>
</tbody>
</table>

Experiential fine arts

<table>
<thead>
<tr>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreign language through the 102 level (by course or placement)</td>
<td>0-6</td>
</tr>
</tbody>
</table>

Open electives

Select any course. 26-36

Total Hours 120

Course offered by the School of the Arts

The minimum number of credit hours required for this degree is 120.
Courses not applicable toward the major

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 101</td>
<td>Foundations of Physics</td>
<td></td>
</tr>
<tr>
<td>PHYS 103</td>
<td>Elementary Astronomy</td>
<td></td>
</tr>
<tr>
<td>PHYS 107</td>
<td>Wonders of Technology</td>
<td></td>
</tr>
<tr>
<td>PHYS 201</td>
<td>General Physics I</td>
<td></td>
</tr>
<tr>
<td>PHYS 202</td>
<td>General Physics II</td>
<td></td>
</tr>
<tr>
<td>PHYS 215</td>
<td>Science, Technology and Society</td>
<td></td>
</tr>
<tr>
<td>PHYS 291</td>
<td>Topics in Physical Science</td>
<td></td>
</tr>
<tr>
<td>PHYS/MHIS 307</td>
<td>The Physics of Sound and Music</td>
<td></td>
</tr>
<tr>
<td>PHYS/ENVS 315</td>
<td>Energy and the Environment</td>
<td></td>
</tr>
<tr>
<td>PHYS 391</td>
<td>Topics in Physics</td>
<td></td>
</tr>
<tr>
<td>PHYZ 101</td>
<td>Foundations of Physics Laboratory</td>
<td></td>
</tr>
<tr>
<td>PHYZ 103</td>
<td>Elementary Astronomy Laboratory</td>
<td></td>
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</tbody>
</table>

The following courses are not applicable toward the physics major requirements but may be used as general electives toward the bachelor's degree:

- PHYS 201: General Physics I
- PHYS 202: General Physics II
- PHYS 215: Science, Technology and Society
- PHYS 291: Topics in Physical Science
- PHYS/MHIS 307: The Physics of Sound and Music
- PHYS/ENVS 315: Energy and the Environment
- PHYS 391: Topics in Physics
- PHYZ 101: Foundations of Physics Laboratory
- PHYZ 103: Elementary Astronomy Laboratory

What follows is a sample plan that meets the prescribed requirements within a four-year course of study at VCU. Please contact your adviser before beginning course work toward a degree.

Freshman year

Fall semester

- CHEM 101: General Chemistry I (satisfies general education A0I for scientific and logical reasoning)
- CHEZ 101: General Chemistry Laboratory I
- MATH 200: Calculus with Analytic Geometry I (satisfies general education quantitative foundations)
- UNIV 111: Focused Inquiry I (satisfies general education UNIV foundations)
- Play course video for Focused Inquiry I
- Experiential fine arts
- General education course

- Term Hours: 15-17

Spring semester

- HUMS 202: Choices in a Consumer Society
- MATH 201: Calculus with Analytic Geometry II
- PHYS 207: University Physics I (satisfies general education BOK for natural sciences and A0I for scientific and logical reasoning)
- UNIV 112: Focused Inquiry II (satisfies general education UNIV foundations)

- Term Hours: 15-16

Fall semester

- CHEM 101: General Chemistry I (satisfies general education A0I for scientific and logical reasoning)
- CHEZ 101: General Chemistry Laboratory I
- MATH 200: Calculus with Analytic Geometry I (satisfies general education quantitative foundations)
- UNIV 111: Focused Inquiry I (satisfies general education UNIV foundations)
- Play course video for Focused Inquiry I
- Experiential fine arts
- General education course

- Term Hours: 15-17

Spring semester

- HUMS 202: Choices in a Consumer Society
- MATH 201: Calculus with Analytic Geometry II
- PHYS 207: University Physics I (satisfies general education BOK for natural sciences and A0I for scientific and logical reasoning)
- UNIV 112: Focused Inquiry II (satisfies general education UNIV foundations)

- Term Hours: 15-16

Sophomore year

Fall semester

- MATH 307: Multivariate Calculus
- PHYS 208: University Physics II
- UNIV 200: Advanced Focused Inquiry: Literacies, Research and Communication (satisfies general education UNIV foundations)
- Foreign language 101

- Term Hours: 15

Spring semester

- MATH 301: Differential Equations
- PHYS 301: Classical Mechanics I
- PHYS 320: Modern Physics
- & PHYS 320: and Modern Physics Laboratory
- Foreign language 102

- Term Hours: 13

Junior year

Fall semester

- PHYS 301: Classical Mechanics I
- PHYS 320: Modern Physics
- General education course (select BOK to complete breadth of knowledge requirement A0I for creativity, innovation and aesthetic inquiry)
- Open electives

- Term Hours: 15-16

Spring semester

- PHYS 335: Experimental Skills for Physicists
- PHYS 340: Statistical Mechanics and Thermodynamics
- Open electives

- Term Hours: 15

Senior year

Fall semester

- PHYS 397: Directed Study
- PHYS 440: Introduction to Condensed Matter Physics
- PHYS 450: Senior Physics Laboratory
- PHYS 470: Introduction to Nanoscience
- Concentration elective

- Term Hours: 15-16

Spring semester

- PHYS 490: Seminar in Conceptual Physics
- PHYS 492: Independent Study (with NANO adviser)
- Concentration elective
- Open elective (complete upper-level if needed)

- Term Hours: 16-17

- Total Hours: 120-125

The minimum number of credit hours required for this degree is 120.

Accelerated B.S. and M.S.

The accelerated B.S. and M.S. program allows academically talented students to earn both the B.S. in Physics and M.S. in Physics and Applied Physics in a minimum of five years by completing approved graduate courses during the senior year of their undergraduate program. Students in the program may count up to 12 hours of graduate courses toward both the B.S. and M.S. degrees. Thus, the two degrees may be earned...
with a minimum of 138 credits rather than the 150 credits necessary if the two degrees are pursued separately.

Students holding these degrees will be more competitive when seeking research and development positions in industry and admission to physics Ph.D. programs. In addition, an M.S. degree is required for most undergraduate teaching positions. The master's program enables students to deepen their understanding of physics while gaining actual experience in research at the frontiers of physics.

**Entrance to the accelerated program**

Interested undergraduate students should consult with their adviser as early as possible to receive specific information about the accelerated program, determine academic eligibility and submit (no later than two semesters prior to graduating with a baccalaureate degree, that is, before the end of the spring semester of their junior year) an Accelerated Program Declaration Form to be approved by the graduate program director. Limited spaces may be available in the accelerated program. Academically qualified students may not receive approval if capacity has been reached.

Minimum qualifications for entrance to this accelerated program include completion of 85 undergraduate credit hours, including PHYS 376 and PHYS 380; an overall GPA of 3.25; and a GPA of 3.25 in physics course work.

Once enrolled in the accelerated program, students must meet the standards of performance applicable to graduate students as described in the "Satisfactory academic progress" section of Bulletin, including maintaining a 3.0 GPA. Guidance to students in an accelerated program is provided by both the undergraduate physics adviser and the graduate adviser specified in the student’s agreed-upon plan of study.

**Admission to the graduate program**

Entrance to the accelerated program enables the student to take the approved shared courses that will apply to the undergraduate and graduate degrees. However, entry into an accelerated program via an approved Accelerated Program Declaration Form does not constitute application or admission into the graduate program. Admission to the graduate program requires a separate step that occurs through a formal application. In order to continue pursuing the master’s degree after the baccalaureate degree is conferred, accelerated students must follow the admission to graduate study requirements outlined in the VCU Bulletin.

**Degree requirements**

The Bachelor of Science in Physics degree will be awarded upon completion of a minimum of 120 credits and the satisfactory completion of all undergraduate degree requirements as stated in the Undergraduate Bulletin.

A maximum of 12 graduate credits may be taken prior to completion of the baccalaureate degree. These graduate credits substitute for required major electives or open elective credits for the undergraduate degree. These courses are shared credits with the graduate program, meaning that they will be applied to both undergraduate and graduate degree requirements.

The graduate physics courses that may be taken as an undergraduate, once a student is admitted to the program, are:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
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</thead>
<tbody>
<tr>
<td>NANO 570</td>
<td>Nanoscale Physics</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 560</td>
<td>Fundamentals of Semiconductor Nanostructures</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 571</td>
<td>Theoretical Mechanics</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 580</td>
<td>Quantum Mechanics</td>
<td>3</td>
</tr>
</tbody>
</table>

**Recommended course sequence/plan of study**

What follows is the recommended plan of study for students interested in the accelerated program beginning in the fall of the junior year prior to admission to the accelerated program in the senior year. The thesis option for the M.S. is shown.

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 340</td>
<td>Statistical Mechanics and Thermodynamics</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 376</td>
<td>Electromagnetism I</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 380</td>
<td>Quantum Physics I</td>
<td>3</td>
</tr>
<tr>
<td>Open electives</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Term Hours:</td>
<td></td>
<td>15</td>
</tr>
</tbody>
</table>

**Senior year**

| Term Hours: | 15 |

**Fifth year**

| Term Hours: | 16 |

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<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>NANO 571</td>
<td>Nanoscale Chemistry</td>
<td>3</td>
</tr>
<tr>
<td>PHYS 697</td>
<td>Directed Research</td>
<td>3</td>
</tr>
<tr>
<td>600-level PHYS elective</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Term Hours:</td>
<td></td>
<td>9</td>
</tr>
</tbody>
</table>

| Term Hours: | 9 |
It is recommended, but not required, that one hour of PHYS 690 be taken as part of the elective credits.

- Physics (PHYS) (p. 4)
- Physics labs (PHYZ) (p. 6)

**Physics**

**PHYS 101. Foundations of Physics. 3 Hours.**
Semester course; 3 lecture hours. 3 credits. For non-science majors. Introduction to the fundamental ideas of physics. The course covers selected topics in mechanics, heat, optics, electricity and magnetism, and modern physics. Not applicable toward the physics major. An optional laboratory may be taken with this course; see PHYS 101.

**PHYS 103. Elementary Astronomy. 3 Hours.**
Semester course; 3 lecture hours (delivered online, face-to-face or hybrid). 3 credits. A descriptive approach to astronomy dealing with basic features of our solar system, our galaxy and the universe. Not applicable toward physics major. An optional laboratory may be taken with this course; see PHYS 103.

**PHYS 107. Wonders of Technology. 4 Hours.**
Semester course; 5 lecture/laboratory/recitation hours. 4 credits. Introduction to physics concepts involved in everyday technological applications. The course covers selected topics in mechanics, heat, optics, electricity and magnetism, and modern physics by depicting their role in common devices. The laboratory focuses on applications of physics principles to everyday real-life situations. Not applicable toward the physics major.

**PHYS 201. General Physics I. 4 Hours.**
Semester course; 3 lecture and 3 laboratory hours. 4 credits. Prerequisite: MATH 151. Designed primarily for life-science majors. Basic concepts of motion, waves and heat. Not applicable toward the physics major.

**PHYS 202. General Physics II. 4 Hours.**
Semester course; 3 lecture and 3 laboratory hours. 4 credits. Prerequisite: PHYS 201 or PHYS 207. Designed primarily for life-science majors. Basic concepts of electricity, magnetism, light and modern physics. Not applicable toward the physics major.

**PHYS 207. University Physics I. 5 Hours.**
Semester course; 3 lecture, 1 recitation and 3 laboratory hours. 5 credits. Prerequisite: MATH 200 or permission of instructor. A vector- and calculus-based introduction to the fundamental concepts of mechanics, heat and wave motion.

**PHYS 208. University Physics II. 5 Hours.**
Semester course; 3 lecture, 1 recitation and 3 laboratory hours. 5 credits. Prerequisite: PHYS 207. Corequisite: MATH 201. A vector- and calculus-based introduction to the fundamentals of electricity, magnetism and optics.

**PHYS 211. Physical Analysis. 3 Hours.**
Semester course; 3 lecture hours. 3 credits. Prerequisites: MATH 201 and PHYS 208. Corequisite: MATH 307. Extends the discussion of physical phenomena introduced in prerequisite courses to introduce topics and skills needed for more advanced physics courses. Topics include applying complex analysis to wave motion and oscillations, methods to solve problems in mechanics and an introduction to classical thermodynamics using multivariate analysis.

**PHYS 215. Science, Technology and Society. 3 Hours.**
Semester course; 3 lecture hours. 3 credits. Examination of scientific breakthroughs that have led to transformational technologies that are continuing to impact society today. Topics include a historical perspective, an understanding of scientific principles and technologies and an examination of how such discoveries have changed society. Not applicable toward physics major.

**PHYS 291. Topics in Physical Science. 1-3 Hours.**
Semester course; 1-3 lecture or laboratory hours. 1-3 credits per semester. A study of a selected topic in physics, astronomy, geology, meteorology or oceanography. Not applicable toward physics major. See the Schedule of Classes for specific topics to be offered each semester and prerequisites.

**PHYS 301. Classical Mechanics I. 3 Hours.**
Semester course; 3 lecture hours. 3 credits. Prerequisites: PHYS 208 with a minimum grade of B or PHYS 211 with a minimum grade of C; and MATH 307. Corequisite: MATH 301. Review of vector calculus. Newtonian mechanics: single particle, oscillations, motion under central forces and dynamics of systems of particles.

**PHYS 302. Classical Mechanics II. 3 Hours.**
Semester course; 3 lecture hours. 3 credits. Prerequisites: PHYS 301 and MATH 301. Motion in noninertial frames, dynamics of rigid bodies, coupled oscillators, continuous systems and wave equations in one dimension.

**PHYS 307. The Physics of Sound and Music. 3 Hours.**
Semester course; 3 lecture hours. 3 credits. Prerequisites: A 100- or 200-level physics course or equivalent and the ability to read music or sing or play a musical instrument, or permission of instructor. Basics of the physics of waves and sound. Fourier synthesis, tone quality, human ear and voice, musical temperament and pitch, physics of musical instruments, electronic synthesizers, sound recording and reproduction, room and auditorium acoustics. Not applicable toward the physics major. Crosslisted as: MHIS 307.

**PHYS 315. Energy and the Environment. 3 Hours.**
Semester course; 3 lecture hours. 3 credits. Enrollment restricted to non-physics majors with junior or senior standing; not applicable to the physics major. A study of society's demands for energy, how it is currently being met, the environmental consequences thereof and some discussion of alternatives. Crosslisted as: ENV 315.

**PHYS 317. Preparing for the MCAT and Medical Sciences. 3 Hours.**
Semester course; 3 lecture hours. 3 credits. Prerequisite: BIOL 152, CHEM 102, PHYS 202 or PHYS 208. This course introduces physics majors to areas of medical practice where physical sciences play a key role. These include but are not limited to radiology and radiation oncology, orthopedics, pulmonology, and electrophysiology. Students will also review key topics in physics and life sciences that are tested on the Medical College Admissions Test. Broadly, these include chemical and physical foundations of biological systems as well as biological and biochemical foundations of living systems.

**PHYS 320. Modern Physics. 3 Hours.**
Semester course; 3 lecture hours. 3 credits. Prerequisites: PHYS 208 and MATH 307. Corequisite: MATH 301. Foundations of modern physics including special relativity, thermal radiation and quantization, wave-particle duality of radiation and matter, Schroedinger equation, atomic, nuclear and particle physics, and molecular structure and spectra. A continuation of PHYS 208.
PHYS 325. Visualization of Physics Using Mathematica. 3 Hours.  
Semester course; 3 lecture hours. 3 credits. Prerequisites: PHYS 208 and MATH 307. Corequisite: PHYS 301 or PHYS 320. Visualization of various areas of physics using the Mathematica language for performing numerical calculations and producing graphics and animations. Examples will be taken from classical mechanics, classical electromagnetism, modern physics, statistical mechanics and condensed matter physics.

PHYS 335. Experimental Skills for Physicists. 3 Hours.  
Semester course; 2 lecture and 2 laboratory hours. 3 credits. Prerequisites: PHYS 320 and PHYZ 320. Practical skills in experimental physics, including use of micro controllers, sensor modules, high-precision positions and opto-electronics. Skills will be used to address engaging and current real-world challenges.

PHYS 340. Statistical Mechanics and Thermodynamics. 3 Hours.  
Semester course; 3 lecture hours. 3 credits. Prerequisites: PHYS 301 and MATH 301. Microscopic theory of temperature, heat and entropy, kinetic theory, multicomponent systems, and quantum statistics. Mathematical relationships of thermodynamics.

PHYS 351. Guided Inquiry for University Physics I. 1.5 Hour.  
Semester course; 1 lecture and 1 recitation hour. 1.5 credits. Prerequisites: PHYS 207 and permission of instructor. Student learning assistants aid in recitation sections of PHYS 207 University Physics I using guided inquiry and group-based activities. Further develops the core skills of PHYS 207. Introduces students to the principles of active and collaborative learning in physics through practical, hands-on problem-solving, class discussions and demonstrations.

PHYS 352. Guided Inquiry for University Physics II. 1.5 Hour.  
Semester course; 1 lecture and 1 recitation hour. 1.5 credits. Prerequisites: PHYS 208 and permission of instructor. Student learning assistants aid in recitation sections of PHYS 208 University Physics II using guided inquiry and group-based activities. Further develops the core skills of PHYS 208. Introduces students to the principles of active and collaborative learning in physics through practical, hands-on problem-solving, class discussions and demonstrations.

PHYS 376. Electromagnetism I. 3 Hours.  
Semester course; 3 lecture hours. 3 credits. Prerequisites: PHYS 301 and MATH 301. Electrostatics, magnetism and electromagnetic properties of matter, Maxwell's equations, electromagnetic waves, boundary conditions, and polarization.

PHYS 377. Electromagnetism II. 3 Hours.  
Semester course; 3 lecture hours. 3 credits. Prerequisite: PHYS 376. Advanced topics in electromagnetism, such as the microscopic theory of magnetism, slowly varying currents, physics of plasmas, electromagnetic properties of superconductors, Maxwell's equations and propagation of electromagnetic waves in bounded media, dispersive media, electromagnetic radiation, electrodynamics of moving charges, and the relativistic formulation of electrodynamics.

PHYS 380. Quantum Physics I. 3 Hours.  
Semester course; 3 lecture hours. 3 credits. Prerequisites: PHYS 301, PHYS 320 and MATH 301, or permission of instructor. Brief introduction to the correspondence between classical and quantum mechanics, Schrödinger wave equation, operator methods in quantum mechanics, angular momentum and conservation laws, solution to harmonic oscillator and the hydrogen atom, magnetic dipole momentum and spin.

PHYS 391. Topics in Physics. 1-3 Hours.  
Semester course; 1-3 lecture hours. 1-3 credits per semester. Maximum total of 6 credits. In-depth study of a selected topic in physics or physics-related technology, usually at a level requiring only elementary algebra. Not applicable toward physics major. See the Schedule of Classes for specific topics to be offered each semester and prerequisites.

PHYS 397. Directed Study. 1-3 Hours.  
Semester course; variable hours. 1-3 credits per semester. Maximum of 3 credits applicable toward physics major requirement; maximum total of 4 credits. Open to nonmajors. Determination of amount of credit and permission of instructor must be obtained before registration of course. Intended to allow nonmajors and majors to examine in detail an area of physics or physics-related technology not otherwise available in upper-level courses. May involve either directed readings or directed laboratory work.

PHYS 417. Topics in Biophysics. 3 Hours.  
Semester course; 3 lecture hours. 3 credits. Prerequisites: PHYS 208, CHEM 102 and BIOL 152. An introduction to biophysics examining many topics in life sciences. The course will introduce how to understand phenomena in life sciences from a quantitative perspective and use physical models for complex systems. Topics include Brownian motion, mechanical and chemical equilibrium, electroatostatics, molecular machines, pattern formation and physical tools in biology.

PHYS 420. Quantum Physics II. 3 Hours.  
Semester course; 3 lecture hours. 3 credits. Prerequisite: PHYS 380 or permission of instructor. Transition rates, addition of angular momentum, multi-electron atoms-ground state, X-ray and optical excitations, time independent perturbation theory, relativistic hydrogen atom and the structure of atoms, collision theory, nuclear structure, elementary particles and their symmetries.

PHYS 422. Optics. 3 Hours.  
Semester course; 3 lecture hours. 3 credits. Prerequisite: PHYS 376 or permission of instructor. Comprehensive study of propagation of light, including geometrical optics, polarization, interference, diffraction, Fourier optics and quantum optics.

PHYS 425. Computational Physics and Data Analysis. 3 Hours.  
Semester course; 3 lecture hours. 3 credits. Prerequisite: PHYS 340. Introduces students to topics in computational physics and computational tools used for data analysis. This course teaches basic skills in programming in the context of applying them to biophysics-related problems. It is assumed that students have no computer programming experience, but have a modest understanding of physical systems.

PHYS 440. Introduction to Condensed Matter Physics. 3 Hours.  
Semester course; 3 lecture hours. 3 credits. Prerequisites: PHYS 340 and 380. Corequisite: PHYS 376. Structure and bonding in solids, phonons, free electron Fermi gas, energy bands, semiconductors, Fermi surface, optical properties and magnetism.

PHYS 450. Senior Physics Laboratory. 3 Hours.  
Semester course; 1 lecture and 4 laboratory hours. 3 credits. Prerequisites: PHYS 301 and 320, and PHYZ 320. Experiments in condensed matter physics with an introduction to the instrumentation and data analysis used in the research laboratory.
PHYS 470. Introduction to Nanoscience. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisite: PHYS 320. An overview and introduction to a wide range of topics in nanoscience and nanotechnology from the point of view of physics, chemistry, engineering and biology. Takes a systems-based approach to demonstrate how different nano-concepts come together to create systems with unique functions and characteristics.

PHYS 480. Particle Physics. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: PHYS 340, PHYS 376 and PHYS 420. Basic concepts of particle physics, including the Dirac equation, lowest-order quantum electrodynamics calculations, scattering amplitudes and cross sections, the weak interaction, processes involving quarks and their symmetries, and quantum chromodynamics.

PHYS 483. Introduction to Astrophysics. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Prerequisites: PHYS 320 and PHYS 340. Pre- or corequisites: PHYS 376 and PHYS 380. Basic concepts of star formation and evolution, galactic structures, and cosmology. Includes stellar atmospheres and interiors, the sun, the Milky Way and other galaxies, and black holes.

PHYS 490. Seminar in Conceptual Physics. 1 Hour.
Semester course; 1 lecture hour. 1 credit. Prerequisites: PHYS 340, PHYS 376, PHYS 380 and PHYZ 320. Restricted to seniors in physics with at least 85 credit hours taken toward the degree. A senior capstone course in physics designed to help students formulate physics-related questions in such a way that they can obtain quantitative answers. Students will describe their results in a senior paper and in an oral presentation.

PHYS 491. Topics in Physics. 3 Hours.
Semester course; 3 lecture hours. 3 credits. Maximum of 3 credits applicable toward physics major requirement; maximum total of 6 credits. An in-depth study of a selected topic in physics. See the Schedule of Classes for specific topics to be offered each semester and prerequisites.

PHYS 492. Independent Study. 1-3 Hours.
Semester course; variable hours. 1-3 credits per semester. Maximum of 3 credits applicable toward physics major requirement; maximum total of 8 credits. Open generally to students of only junior or senior standing who have acquired at least 12 credits in the departmental discipline. Determination of the amount of credit and permission of instructor and department chair must be procured prior to registration of the course. Independent projects in experimental or theoretical physics.

Physics labs

PHYZ 101. Foundations of Physics Laboratory. 1 Hour.
Semester course; 2 laboratory hours. 1 credit. Corequisite: PHYS 101. An optional laboratory consisting of experiments and activities correlated with PHYS 101.

PHYZ 103. Elementary Astronomy Laboratory. 1 Hour.
Semester course; 2 laboratory hours. 1 credit. Pre- or corequisite: PHYS 103. An optional laboratory course consisting of experiments and activities related to PHYS 103.

PHYZ 320. Modern Physics Laboratory. 1 Hour.
Semester course; 3 laboratory hours. 1 credit. Pre- or corequisite: PHYS 320. Experimental work correlated with PHYS 320.