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

Student learning outcomes
Upon completing this program, students will know and know how to do the following:

• Demonstrate broad and core science proficiency
• Demonstrate competency in at least two sciences or in a non-science area
• Apply learning to selection and pursuit of professional or graduate career objective
• Demonstrate proficiency in communication of scientific or research findings
• Demonstrate ability to apply the scientific method/approach to professional problems
• Demonstrate appreciation of the interrelation of core sciences to interdisciplinary problems

Special requirements
The Bachelor of Science in Science requires a minimum of 120 credits.

Along with the general education requirements of the undergraduate programs and the College of Humanities and Sciences for a Bachelor of Science degree, this curriculum requires 27 credits in foundation science and mathematics courses and 34 credits in supplemental courses in the concentration. In preparation for the required mathematical sciences courses, all students must take the Mathematics Placement Test.

Science majors are strongly encouraged to select a minor in an area different from their area of concentration that will complement their career interests and contribute additional upper-level credits to their curriculum.

Grade requirements
A minimum grade of C is required in each prerequisite course:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEM 100</td>
<td>Introductory Chemistry (if required through placement test)</td>
<td>3</td>
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<tr>
<td>CHEM 101</td>
<td>General Chemistry I</td>
<td>3</td>
</tr>
<tr>
<td>CHEM 102</td>
<td>General Chemistry II</td>
<td>3</td>
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<tr>
<td>CHEM 301</td>
<td>Organic Chemistry</td>
<td>3</td>
</tr>
<tr>
<td>CHEM 302</td>
<td>Organic Chemistry</td>
<td>3</td>
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A minimum grade of C is required in the following courses before enrollment in advanced BIOL courses:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOL 151 &amp; BIOZ 151</td>
<td>Introduction to Biological Sciences I and Introduction to Biological Science Laboratory I</td>
<td>4</td>
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</table>

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

Course | Title | Hours
|-------|-------|---
| BIOL 152 & BIOZ 152 | Introduction to Biological Sciences II and Introduction to Biological Science Laboratory II | 4 |
| BIOL 300 | Cellular and Molecular Biology | 3 |

Select 12-13 credits from general education foundations and 17-18 credits from areas of inquiry: 30

Major requirements

• Major core requirements
  INSC 490 | Capstone Research Experience in Interdisciplinary Science | 3 |

• Additional major requirements
  ENV 301 | Introduction to Meteorology (or upper-level science elective) | 3 |
| ENV 310 | Introduction to Oceanography (or upper-level science elective) | 3 |
| MATH 201 | Calculus with Analytic Geometry II | 4 |
| MATH 301 | Differential Equations | 3 |
| MATH 307 | Multivariate Calculus | 4 |

• Concentration requirements
  PHYS 208 | University Physics II | 5 |
| PHYS 301 | Classical Mechanics I | 3 |
| PHYS 320 | Modern Physics | 4 |
| & PHYZ 320 | and Modern Physics Laboratory | |
| PHYS 450 | Senior Physics Laboratory | 3 |

• Major electives
  Select an additional eight to nine credits from the following: 8-9
  | CHEM 102 | General Chemistry II & General Chemistry Laboratory II |
| OPER 327 | Mathematical Modeling |
| PHYS 103 | Elementary Astronomy & PHYZ 103 | and Elementary Astronomy Laboratory |
| PHYS/MHIS 307 | The Physics of Sound and Music |

Or any course allowable for the B.S. in Physics, or a science elective approved by adviser

Ancillary requirements

Select one of the following: 4

| BIOL 101 | Biological Concepts & BIOZ 101 | and Biological Concepts Laboratory |
| BIOL 103 | Global Environmental Biology |
| BIOL 151 & BIOZ 151 | Introduction to Biological Sciences I and Introduction to Biological Science Laboratory I |
| BIOL 152 & BIOZ 152 | Introduction to Biological Sciences II and Introduction to Biological Science Laboratory II |
| HUMS 202 | Choices in a Consumer Society | 1 |
Science, Bachelor of Science (B.S.) with a concentration in physics

CHEM 101 & CHEZ 101 General Chemistry I and General Chemistry Laboratory I (both satisfy general education BOK for natural sciences and AOI for scientific and logical reasoning)

MATH 151 Precalculus Mathematics (satisfies general education quantitative foundations)

MATH 200 Calculus with Analytic Geometry I

PHYS 207 University Physics I (satisfies general education BOK for natural sciences and AOI for scientific and logical reasoning)

Experiential fine arts 1 1-3

Foreign language through the 102 level (by course or placement) 0-6

Open electives

Select any course. 27-36

Total Hours 120

Course offered by the School of the Arts

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

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 & CHEZ 101 General Chemistry I and General Chemistry Laboratory I (both satisfy general education BOK for natural sciences and AOI for scientific and logical reasoning)

UNIV 112 Play course video for Focused Inquiry II

Focused Inquiry II (satisfies general education UNIV foundations) 3

Term Hours: 17

Sophomore year

Fall semester

Select one of the following: 4

BIOL 101 Biological Concepts
& BIOZ 101 and Biological Concepts Laboratory

BIOL 103 Global Environmental Biology

BIOL 151 Introduction to Biological Sciences I
& BIOZ 151 and Introduction to Biological Science Laboratory I

BIOL 152 Introduction to Biological Sciences II
& BIOZ 152 and Introduction to Biological Science Laboratory II

MATH 201 Calculus with Analytic Geometry II

PHYS 208 University Physics II

UNIV 200 Inquiry and the Craft of Argument (satisfies general education UNIV foundations)

Term Hours: 16

Spring semester

MATH 301 Differential Equations

PHYS 320 Modern Physics
& PHYZ 320 and Modern Physics Laboratory

General education course (select BOK to satisfy breadth of knowledge requirement and AOI for creativity, innovation and aesthetic inquiry) 3

General education course (select BOK to satisfy breadth of knowledge requirement and AOI for diversities in the human experience) 3-4

Term Hours: 13-14

Junior year

Fall semester

PHYS 103 or OPER 327 Elementary Astronomy or Mathematical Modeling

PHYS 301 Classical Mechanics I

PHYS 307 The Physics of Sound and Music (fulfills experiential fine arts gen ed requirement) 3

Foreign language 101, upper-level open elective or minor elective 3

Open elective 3

Term Hours: 15

Spring semester

ENVS 301 Introduction to Meteorology (or upper-level science elective)

ENVS 310 Introduction to Oceanography (or upper-level science elective)

PHYS 450 Senior Physics Laboratory

Foreign language 102, upper-level open elective or minor elective 3

Term Hours: 15
Physics, Bachelor of Science (B.S.) with a concentration in physics

Semester course; 3 lecture hours. 3 credits. Corequisite: MATH 201. 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. 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.

The minimum number of credit hours required for this degree is 120.
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 S 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. 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, Schroedinger wave equation, operator methods in quantum mechanics, angular momentum and conservation laws, solution to harmonic oscillator and the hydrogen atom, magnetic dipole moment 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, electrostatics, 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.