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

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>Description</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEM 100</td>
<td>Introductory Chemistry (if required through placement test)</td>
<td>3</td>
</tr>
<tr>
<td>CHEM 101</td>
<td>General Chemistry</td>
<td>3</td>
</tr>
<tr>
<td>CHEM 102</td>
<td>General Chemistry</td>
<td>3</td>
</tr>
<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>
</tr>
</tbody>
</table>

A minimum grade of C is required in the following courses before enrollment in advanced BIOL courses:

<table>
<thead>
<tr>
<th>Course</th>
<th>Description</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOL 151</td>
<td>Introduction to Biological Sciences I and Introduction to Biological Science Laboratory I</td>
<td>4</td>
</tr>
<tr>
<td>&amp; BIOZ 151</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BIOL 152</td>
<td>Introduction to Biological Sciences II and Introduction to Biological Science Laboratory II</td>
<td>4</td>
</tr>
<tr>
<td>&amp; BIOZ 152</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BIOL 300</td>
<td>Cellular and Molecular Biology</td>
<td>3</td>
</tr>
</tbody>
</table>

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

General education requirements

University Core Education Curriculum (minimum 21 credits)

<table>
<thead>
<tr>
<th>Course</th>
<th>Description</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNIV 111</td>
<td>Play course video for Focused Inquiry I</td>
<td>3</td>
</tr>
<tr>
<td>UNIV 112</td>
<td>Play course video for Focused Inquiry II</td>
<td>3</td>
</tr>
<tr>
<td>UNIV 200</td>
<td>Inquiry and the Craft of Argument</td>
<td>3</td>
</tr>
</tbody>
</table>

Approved humanities/fine arts                                     | 3       |
Approved natural/physical sciences                               | 3-4     |
Approved quantitative literacy                                    | 3-4     |
Approved social/behavioral sciences                               | 3-4     |
Total Hours                                                        | 21-24   |

Additional College of Humanities and Sciences requirements

(11-23 credits)

<table>
<thead>
<tr>
<th>Course</th>
<th>Description</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>HUMS 202</td>
<td>Choices in a Consumer Society</td>
<td>1</td>
</tr>
</tbody>
</table>

Approved H&S diverse and global communities                        | 3       |
Approved H&S human, social and political behavior (fulfills University Core social/behavioral sciences) | |
Approved H&S literature and civilization (fulfills University Core humanities/fine arts) | |
Approved H&S science and technology (fulfills University Core natural/physical sciences) | |
Approved H&S general education electives                           | 6-8     |
Experiential fine arts                                              | 1-3     |
Foreign language through the 102 level (by course or placement)     | 0-8     |
Total Hours                                                        | 11-23   |

1 Course offered by the School of the Arts

Major requirements

Foundation courses

Select one of the following: 4

<table>
<thead>
<tr>
<th>Course</th>
<th>Description</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOL 101</td>
<td>Biological Concepts and Biological Concepts Laboratory</td>
<td></td>
</tr>
<tr>
<td>&amp; BIOZ 101</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BIOL/ENVS 103</td>
<td>Environmental Science</td>
<td></td>
</tr>
<tr>
<td>BIOL 151</td>
<td>Introduction to Biological Sciences I and Introduction to Biological Science Laboratory I</td>
<td>4</td>
</tr>
<tr>
<td>&amp; BIOZ 151</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BIOL 152</td>
<td>Introduction to Biological Sciences II and Introduction to Biological Science Laboratory II</td>
<td>4</td>
</tr>
<tr>
<td>&amp; BIOZ 152</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHEM 101</td>
<td>General Chemistry and General Chemistry Laboratory I</td>
<td>4</td>
</tr>
<tr>
<td>&amp; CHEZ 101</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ENVS 301</td>
<td>Introduction to Meteorology (or upper-level science elective)</td>
<td>3</td>
</tr>
<tr>
<td>ENVS 310</td>
<td>Introduction to Oceanography (or upper-level science elective)</td>
<td>3</td>
</tr>
</tbody>
</table>

Select one of the following: 1-3
Science, Bachelor of Science (B.S.) with a concentration in physics

INSC 490  Capstone Research Experience in Interdisciplinary Science
Or an approved capstone from another science major (biology, chemistry or physics)

MATH 151  Precalculus Mathematics (or placement)
MATH 200  Calculus with Analytic Geometry
PHYS 207  University Physics I

Supplemental courses
MATH 201  Calculus with Analytic Geometry
MATH 301  Differential Equations
MATH 307  Multivariate Calculus
PHYS 208  University Physics II
PHYS 301  Classical Mechanics I
PHYS 320  Modern Physics
& PHYZ 320  and Modern Physics Laboratory
PHYS 450  Senior Physics Laboratory

Select an additional eight to nine credits from the following:
CHEM 102  General Chemistry
& CHEZ 102  and General Chemistry Laboratory I
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

Total Hours 63-65

Open electives
Select 13-27 open elective credits 13-27

Total minimum requirement 120 credits

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
& CHEZ 101  and General Chemistry Laboratory I
MATH 151  Precalculus Mathematics
or MATH 200  or Calculus with Analytic Geometry
UNIV 101  Introduction to the University
UNIV 111  Focused Inquiry I
Play course video for Focused Inquiry I
Approved diverse and global communities
Approved literature and civilization

Term Hours: 15

Spring semester
CHEM 102  General Chemistry
& CHEZ 102  and General Chemistry Laboratory II
HUMS 202  Choices in a Consumer Society

Sophomore year
Fall semester
Select one of the following:
BIOL 101  Biological Concepts
& BIOZ 101  and Biological Concepts Laboratory
BIOL 103  Environmental Science
or ENVS 103
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
or MATH 307
PHYS 208  University Physics II
UNIV 200  Inquiry and the Craft of Argument

Term Hours: 16

Spring semester
MATH 301  Differential Equations
PHYS 320  Modern Physics
& PHYZ 320  and Modern Physics Laboratory
Approved human, social and political behavior 3-4
Approved literature and civilization 3

Term Hours: 13-14

Junior year
Fall semester
PHYS 103  Elementary Astronomy
or OPER 327  or Mathematical Modeling
PHYS 301  Classical Mechanics I
PHYS 307  The Physics of Sound and Music (fulfills experiential fine arts gen ed requirement)
Approved General Education elective 3-4
Foreign language (101), upper-level open elective or minor elective 3-4

Term Hours: 15-17

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
Approved science and technology (if not already fulfilled by BIOL 101 or PHYS 103) 0-3
Foreign language (102), upper-level open elective or minor elective 3-4
Upper-level open elective or minor elective 3

| Term Hours: | 15-19 |

**Senior year**

**Fall semester**

| BIOL 317   | Ecology or Energy and the Environment 3 |
| ENVS 315   | or Environmental Pollution |
| PHYS 315   | or Environmental Pollution |
| BIOL 332   | or Environmental Pollution |
| ENVS 330   | or Environmental Pollution |
| ENVS 105   | Physical Geology 3 |
| or         | or Physical Geography: Geomorphology and Soils |
| URSP 204   | or Physical Geography: Geomorphology and Soils |
| URSZ 204   | Physical Geography Laboratory: Geomorphology and Soils 1 |
| Approved General Education elective 3 |
| Experiential fine arts (if not fulfilled by PHYS/MHIS 307, upper-level recommended) 1-3 |
| Upper-level open elective or minor elective 3 |
| Term Hours: | 14-16 |

**Spring semester**

Select one of the following: 1-3

| INSC 490   | Capstone Research Experience in Interdisciplinary Science |
| Or approved capstone from another science major (biology, chemistry or physics) |
| Upper-level open electives or minor electives 11-12 |
| Upper-level science elective 3 |
| Term Hours: | 15-18 |
| Total Hours: | 120-132 |

**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 PHYZ 101L.

**PHYS 103. Elementary Astronomy. 3 Hours.**
Semester course; 3 lecture hours. 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 PHYZ 103L.

**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. 4 Hours.**
Continuous courses; 3 lecture and 3 laboratory hours. 4-4 credits. Prerequisite: MATH 151. Completion of PHYS 201 to enroll in PHYS 202. Designed primarily for life-science majors. First semester: basic concepts of motion, waves and heat. Second semester: basic concepts of electricity, magnetism, light and modern physics. Not applicable toward physics major.

**PHYS 202. General Physics. 4 Hours.**
Continuous courses; 3 lecture and 3 laboratory hours. 4-4 credits. Prerequisite: MATH 151. Completion of PHYS 201 to enroll in PHYS 202. Designed primarily for life-science majors. First semester: basic concepts of motion, waves and heat. Second semester: basic concepts of electricity, magnetism, light and modern physics. Not applicable toward 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 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 and MATH 307. Corequisite: MATH 301. Review of vector calculus. Newtonian mechanics: single particle, oscillations, motion under central forces and dynamics of a 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. Enrollments 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: ENVS 315.

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. Prerequisite: PHYS 301, PHYS 320 or permission of instructor. 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 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 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 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 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 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 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.