College of Science
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The University of Notre Dame awarded its first bachelor of science degree in 1865. Before that time, courses had been taught in mathematics (from 1842), in biology (from 1844), and in chemistry (from 1850). In 1867, a program in general science was formulated. Subsequently, specialized programs were added, leading to the degree of bachelor of science in botany and in zoology (both now covered by one degree in biological sciences), in environmental sciences, in biochemistry, in chemistry, in physics, in mathematics, and in preprofessional studies.

Departments of the College of Science

The Department of Biological Sciences, located in the Galvin Life Science Center, has laboratories well equipped for courses of undergraduate and graduate instruction and research. The collections of museum specimens, including the Nieuwland-Greene Herbarium, are available for use in teaching and research. X-ray equipment and several radioactive sources also are available. The facilities include darkrooms, a green house, controlled environmental rooms, scanning and transmission electron microscopes, confocal optical microscopes, and extensive data storage and retrieval equipment.

The Freimann Life Science Center provides additional laboratories, vertebrate animal care, and associated specialized modern research facilities to serve the expanding needs of the life sciences at Notre Dame.

The recently completed Hank Center for Environmental Science adds more than 20,000 square feet of state-of-the-art research space for aquatic and environmental biology that includes greenhouses, wet laboratories, a field sample processing room, and a fully equipped workshop.

The Department of Chemistry and Biochemistry, located in Nieuwland Science Hall and St. John of the Cross Hall of Chemistry and Biochemistry, has laboratories devoted to research and instruction in several areas of chemistry: physical, inorganic, organic, and biochemistry. The laboratories are equipped with all necessary facilities for undergraduate students, graduate students, postdoctoral investigators, and faculty. The facilities for experimental research include many pieces of equipment, such as infrared, ultraviolet, Raman, mass, photoelectron, nuclear magnetic resonance, and electron paramagnetic resonance spectrometers; apparatus for dielectric measurements; electrochemical apparatus; gas liquid chromatographic adsorption equipment, both analytical and preparative; special apparatus for studying mechanisms and rates of reactions; special apparatus for synthesis and structural studies on biomolecules, including cell culture facilities for generating recombinant biomacromolecules, etc. For theoretical work, the computational facilities are available, including access to a Graphics Workstation Cluster. The facilities of the Radiation Research Laboratory are used by some faculty of the chemistry department for research in physical chemistry.

The Department of Mathematics is housed in Hayes-Healy Center/Hurley Hall, conveniently located in the central campus. The facilities for undergraduate and graduate instruction and research in mathematics include a first-rate research library; a faculty room; offices for the faculty, postdoctoral investigators, and other visitors, graduate students, and staff; several research seminar and conference rooms; and several large classrooms with state-of-the-art media capability.

The Department of Physics, located in Nieuwland Science Hall, has classrooms and laboratories for both undergraduate and graduate instruction and for research. There are facilities for experimental work in astrophysics, biophysics, condensed-matter physics, elementary particle physics, and nuclear physics. There are three atomic spectroscopy laboratories, and some additional use is made of facilities at Argonne National Laboratory. Elementary particle experiments are done at the Stanford and Fermi national laboratories, and at CERN in Geneva, Switzerland. Detector development for the major accelerators is also being done in the department. The Nuclear Structure Laboratory has a tandem accelerator with a heavy ion capacity and all necessary detection equipment. A variety of solid state facilities are available for the study of metals, high Tc superconductors, and semiconductors. Off-site facilities at Argonne, the National High Magnetic Field Laboratory, and the National Institutes of Standards and Technology are also heavily used. Notre Dame is a partner in the Large Binocular Telescope project, now in construction. This will be one of the most capable facilities in the world for cutting-edge cosmology and astrophysics research. Research is conducted in many major areas of theoretical physics, including all of the above areas as well as statistical mechanics, field theory, general relativity, and astrophysics. The department has a substantial machine shop and research library and a variety of staff technicians. Many faculty members and research groups have computing facilities, and all have access to the Office of Information Technologies' very large computers.

The Department of Preprofessional Studies is located in Nieuwland Science Hall. All courses for students enrolled in the preprofessional program and collegiate sequence programs are provided by the other departments of the College of Science and the other colleges of the University.

Undergraduate Education

The aim of the program of undergraduate education in the College of Science is to produce intellectually able graduates who are grounded in the broad fundamental principles of the basic sciences, versed in the advanced concepts of their chosen scientific discipline and educated in the humanistic and social studies, including theology. Each graduate should be a good scientist in his or her own field, a fully developed person, aware of his or her responsibilities to society and prepared to participate fruitfully in the affairs of society.

Education in science at Notre Dame is a coordinated program involving the basic sciences, the chosen advanced science, and the humanistic and social studies, including theology and philosophy. In this education, the student should acquire a thorough, integrated, and broad understanding of the fundamental knowledge in his or her field, a competence in orderly analytical thinking, and the capacity to communicate ideas to others, orally and in writing. This system of education is so arranged to develop in each student the desire and habit of continuing to learn after graduation, advancing over the years to higher levels of professional and personal stature and keeping abreast of the changing knowledge and problems of his or her profession.

Emphasis is placed on fundamental principles so that the students can develop abilities to apply these principles to the solution of new problems never before encountered by society, to the discovery of new things and to the invention of devices not learned about in books. Notre Dame stresses basic concepts useful in later learning rather than masses of particular facts and data that can better be found in books at the time of need.
Curricula and Degrees

The College of Science offers curricula leading to the degree of bachelor of science in each of five undergraduate departments:

- Biological Sciences
- Chemistry and Biochemistry
- Mathematics
- Physics
- Preprofessional Studies

The following are degree programs offered by these departments:

- Biochemistry
- Biological Sciences
- Chemistry
- Chemistry combined with Business
- Chemistry combined with Computing
- Environmental Sciences
- Mathematics
- Mathematics (combined with other programs)
- Physics
- Physics (combined with other programs)
- Preprofessional Studies
- Science-Business
- Science-Computing
- Science-Education

These degree programs are described in detail in later sections of this Bulletin.

See also the bachelor of science degree programs offered by the College of Engineering:

- Computer Science
- Environmental Geosciences

Each College of Science student must enroll in the department of his or her major beginning with the sophomore year. However, students may change freely from one program to another within their departmental major and may also change departments at any time up through the seventh class day of their senior year.

The College of Science maintains a Web site at www.science.nd.edu. Further information related to programs offered by the college may be found at that location.

Listed below are the allowed options for students interested in double science majors, double majors between colleges, second majors in the College of Science, and supplementary majors and minors in the College of Arts and Letters.

Students pursuing one of these combination programs must have superior scholastic ability and be formally accepted by the dean of both colleges involved. Approval will not be granted if there is substantial overlap between the two programs.

*Note:* Courses taken toward the completion of another major or supplementary major or minor or concentration requirement may not also be counted toward the student's other majors or minors or concentrations or University requirements.

**Double Science Majors.** In certain instances, students will have the option of pursuing majors in two departments of the College of Science. Details on the double science major option and lists of combinations that are normally approved are found under “Special Programs,” later in this section of the Bulletin.

**Dual Degree.** Notre Dame students pursuing majors in two of the undergraduate colleges may qualify for a five-year dual-degree program.

The requirements for a dual degree generally are as follows: The student completes all of the university requirements, all of the requirements for both colleges, all of the requirements for both majors, and the total number of degree credits specified for a dual degree in the two colleges. While the total number of hours required does depend on the two major programs, the minimum required total number of degree credits is set to be 30 degree credits beyond the college total for the college with the greatest required number of degree credits. For students completing a dual degree in the College of Science and the College of Arts and Letters, the minimum number is thus 154 hours.

**Double Majors in Two Colleges.** Qualified Notre Dame students pursuing majors in one of the other undergraduate colleges or schools may add another major in the College of Science. Additionally, qualified Notre Dame students pursuing a major in the College of Science may also add another major in one of the other undergraduate colleges or schools.

The requirements for a double major between colleges generally are as follows: The student completes all the University requirements, the requirements of his or her college or school, and the requirements of both majors. In general, a single course may not satisfy requirements for both majors.

**Supplementary Majors and Minors.** Qualified Notre Dame students pursuing majors in the College of Science may add a supplementary major or minor. Options include programs offered through the College of Arts and Letters and the Environmental Geosciences minor offered through the College of Engineering.

Not all supplementary major programs are open to science students; e.g., science students may not add the Arts and Letters Preprofessional Studies supplementary major nor the Computer Applications supplementary major.

**Supplementary Majors, Minors, and Concentrations in the College of Science.** In the College of Science, the term “second major” is used for a supplementary major. Three departments offer a second major program specifically for students in the other colleges: Mathematics as a second major, physics as a second major, and environmental sciences as a second major. For details, see the departmental sections of this Bulletin.

There are no minor programs in the College of Science.

The only concentration programs offered in the College of Science are those for mathematics majors. For details, see the departmental sections of this Bulletin.

**Combination Five-Year Program with the Mendoza College of Business.** The College of Science and the Mendoza College of Business have established a competitive cooperative program in which a student may simultaneously earn a bachelor of science and a master of business administration degree. The program is structured so that the student who has completed the three years of a science bachelor’s degree program, if accepted, completes the master of business administration and the bachelor of science in a major in the College of Science in a summer session and two subsequent academic years.

Students who wish to pursue this program should have a superior scholastic record in their major program and must make application to, and be accepted by, the M.B.A. program.

The general sequence of courses in the five-year Science-M.B.A. program may be found under “Dual Degree Program with the Mendoza College of Business,” later in this section of the Bulletin.
University and College Requirements

A minimum of 124 credit hours is required for graduation from the College of Science. A minimum of 60 credit hours must be in science; however, each department may specify more than 60 credit hours for any of its programs.

All College of Science majors must fulfill University requirements, which include:

<table>
<thead>
<tr>
<th>Course</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>FYC</td>
<td>3</td>
</tr>
<tr>
<td>*Theology</td>
<td>6</td>
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<tr>
<td>*Philosophy</td>
<td>6</td>
</tr>
<tr>
<td>*History</td>
<td>3</td>
</tr>
<tr>
<td>*Social Science</td>
<td>3</td>
</tr>
<tr>
<td>*Fine Arts or Literature</td>
<td>3</td>
</tr>
</tbody>
</table>

* One of these courses must be a University Seminar 180.

In addition, all College of Science majors must take courses in:

- Chemistry (113, 114 or 117, 118 or 125, 126)
- Mathematics (119, 120 or 125, 126 or 165, 166)
- Physics (131, 132 or 151, 152 or 221, 222).

The appropriate sequence for a student depends on the student's major.

The College of Science requires language proficiency through intermediate level in one of the following languages: Arabic, Chinese, French, German, Greek, Irish, Italian, Japanese, Latin, Portuguese, Russian, and Spanish. Students may complete the language requirement by either completing a course taught at intermediate level or by demonstrating proficiency through placement examination. The college office maintains a list of language courses at intermediate level. (See the college Web site, www.science.nd.edu.)

Students with no previous background in a language should start with a beginning-level course. They take typically either nine credits over a three-semester period or two semesters of an intensive language sequence (8–10 credits total). Placement for students with some background in French, Spanish, Latin or German will be made only by examination (1) through the Advanced Placement test, (2) through the SAT II Subject test (French and Spanish), (3) through the International Baccalaureate Program or (4) through the Notre Dame departmental placement examinations. A maximum of six credits of placement can be granted for previous study in a given language. Thus, typically, College of Science students who have completed the language requirement will count from six to 10 credits in language toward the 124 credits required for graduation.

The College of Science will count a maximum of three credit hours from the following types of activity courses:

- Band (Marching and Concert)
- Orchestra
- Chorale
- Glee Club
- Liturgical Choir
- Folk Choir
- Music Lessons and Ensembles
- Dance
- Debate
- Social Concerns Seminar (including THEO 360)
- Science in the Classroom (SC 495)

No more than one credit hour total from any of these courses may be counted toward the degree per semester. Additionally, a maximum of six credit hours of upper-level (300- or 400-level) ROTC courses can be counted toward the 124-credit-hour requirement. These courses will be counted as free electives.

Not all science courses will count toward degree credit or science elective credit for science majors. The survey science courses offered as options for non-science majors for their University science requirement will not count as a science elective or toward the minimum science credit hour requirement. Because of overlap in content with required courses for science majors, many of these courses will also not count toward the degree credit requirement (see “Science Degree Credit,” later in this section of the Bulletin).

Some major programs have a science elective requirement. Recommended science electives for particular science majors are found on the college's Web site, www.science.nd.edu. For a course to be a science elective, it must meet the following rules: (1) It is offered through one of the departments of the College of Science or through the college itself. (2) It is major's level; that is, other science majors are required to take this course to meet a major requirement or it has a prerequisite course that is offered for science majors, or the Bulletin description for the course states that it is a science elective in the College of Science. Finally, note the departments may place additional restrictions on allowed science electives, e.g., in the Department of Biological Sciences, a science elective must be a non-biology course.

All College of Science courses offered by a major program must be taken at the University of Notre Dame. If a student wants to take a course outside Notre Dame for credit toward the Notre Dame degree, prior approval of the dean's office must be obtained. This does not apply to the courses taken by a transfer student prior to attending Notre Dame.

Advising. All Notre Dame science majors have been assigned an advisor in the department of their major. All advisors are members of the faculty of the College of Science. In some departments, the director of undergraduate studies for the department advises all students. In others, the director of undergraduate studies or the department office may be contacted to find out the name of the student's advisor. A complete list of names of advisors is kept on the science Web site.

Notre Dame students who have questions concerning the choice of a major or considering a change of major are urged to make appointments with the advisors of the departments involved. Students needing help choosing from similar majors may request an advising appointment with the associate dean of the College of Science, 174 Hurley Hall.
Student Organizations and Activities

In addition to participation in University-wide student activities, the undergraduate students of the College of Science may participate in activities directly related to science, including the undergraduate departmental science organizations: the Biology Club, the Notre Dame Chapter of Student Affiliates of the American Chemical Society, the Mathematics Club, the Society of Physics Students, the Premed Club (preprofessional), the Prevet Club, the Science-Business Club, and the Notre Dame Chapter of Alpha Epsilon Delta (premedical honorary fraternity).

Student Council. The Student Council of the College of Science is composed of representatives of the majors of the College of Science. The student council serves as the official body representing the undergraduate students before the administration of the College of Science.

Student Awards and Prizes

The Dean's Award. Presented to the outstanding graduating senior in the College of Science in recognition of exemplary personal character, leadership, service, and outstanding achievement. Selected by the dean and associate dean.

Outstanding Senior Biological Scientist(s). To the senior(s) who has/have demonstrated the most promise in the biological sciences as evidenced by both academic performance and research participation.

American Institute of Chemists Award. For scholastic achievements, ability, and potential advancement in the chemical profession.

Merck Index Award. For outstanding achievements in chemistry or biochemistry.

Nobert L. Weech Awards. Given to two chemistry or biochemistry majors in the junior year for outstanding achievement in academics or research.

Outstanding Biochemist Award. For leadership, academic achievements, research and scholarship in biochemistry.

Outstanding Chemist Award. For academic and research achievements in chemistry as an undergraduate.

William R. Wischerath Outstanding Chemistry Major Award. For academic achievements of a graduating senior chemistry major.

Chemistry-Education Award. For academic achievement in preparation for teaching of chemistry in a secondary education system.

The General Electric Prizes for Honors Majors in Mathematics. Awarded to senior honors majors in the Department of Mathematics who, in the opinion of the members of the faculty, excelled in mathematics during their undergraduate career.

The General Electric Prizes for Majors in Mathematics. A similar award to senior majors.

The George Kolettis Award in Mathematics. An award established by friends of the late Prof. George Kolettis, for a graduating senior who excelled in mathematics and contributed notably to the esprit de corps of the mathematics student body.

The Aumann Prize for First Year Students in Mathematics. A prize given by Ms. Monika Cara-donna in honor of her father, Prof. Georg Aumann, awarded on the basis of a competition among First Year honors mathematics students.

The Norman and Beatrice Haaser Mathematics Scholarships. These scholarships, made possible by the generosity of Professor and Mrs. Haaser, are awarded to worthy, needy students majoring in mathematics.

R. Catesby Taliaferro Competition for Sophomore Mathematics Honors Students. Friends and students of the late Professor Taliaferro established this prize, which is awarded to a sophomore mathematics major on the basis of an essay submitted by the student.

J & C Sophomore Award in Mathematics. Exemplary performance in mathematics classes by a non-honors math major sophomore female or minority (African-American, Asian, Hispanic, Native American) student.

Outstanding Senior Physics Major. This award is given to the outstanding senior physics major who, in the judgment of the departmental faculty, shows the most promise for a distinguished career in physics. Course grades, the opinion of those who have taught the candidates, and any research performance are considered in making the award.

Physics Outstanding Undergraduate Research Award. A monetary award given for excellence in research to an undergraduate physics major.

DiNardo Award. To the outstanding junior preprofessional student.

Emil T. Hofmann Scholarships. To six outstanding students pursuing premedical studies.

J.C. Lungren, M.D., Scholarships. Awarded to three outstanding science preprofessional students.

The Lawrence H. Baldinger Award. To seniors in the preprofessional program who excelled in scholarship, leadership, and character.

The Patrick J. Niland, M.D., Award. To an outstanding preprofessional student.

The Samuel Chmell, M.D., Award. To an outstanding junior preprofessional student.

The Samuel Chmell, M.D., Award. To seniors in the preprofessional program who excelled in scholarship, leadership, and character.

The Lawrence H. Baldinger Award. To seniors in the preprofessional program who excelled in scholarship, leadership, and character.

The Patrick J. Niland, M.D., Award. To an outstanding preprofessional student.

The Samuel Chmell, M.D., Award. To an outstanding senior in preprofessional studies who exemplifies high academic achievement and uncompromising integrity within the program.

The Chairman's Award. To a senior with a keen social awareness who shows great promise as a concerned physician.
Special Opportunities

Arts and Letters/Science Honors Program. In the fall of 1983, the University inaugurated an honors program for a small number of outstanding students in the College of Arts and Letters and the College of Science. A limited number of students with academic intents for each college are invited to apply for this program in the spring before their first year. Although selection criteria include the promise of outstanding academic performance as demonstrated by standardized test scores and high school performance, the program is looking for more than mere academic ability. It hopes to identify students with broad interests in science and the humanities.

The program offers honors sections to fulfill most of the University and college requirements in the students’ first and sophomore years. At present, there are honors sections of theology and philosophy, physics, mathematics, core course, literature, and social science. Since most of these sections are restricted to honors students, they are smaller than non-honors sections and some are taught in a seminar format. Honors Program students meet the seminar requirement of the University by taking the first-year Honors Program Seminar. The teachers for honors sections are chosen from among the most outstanding teachers in each college. After the first year, each student’s academic work will be mainly centered in his or her major field of study, but a small number of elective honors courses also will be offered. In the senior year, a combined arts and letters/science seminar is required in the fall semester. For students in the College of Science, special emphasis is placed on involving the student with ongoing research programs as early as their sophomore year but more typically in their junior and senior years. Each student is guided by a faculty member who functions as his or her research advisor and mentor. Thus, students and faculty meet regularly in both formal and informal settings, and this interaction leads to the completion of the honors thesis during the senior year in the student’s major field of study.

In addition to the focused academic features of the Honors Program, students are offered opportunities each semester for informal evening colloquia on topics of broad intellectual interest. These and other occasional events allow the mutually enlightening exchanges between students and faculty that are less possible in the formal settings of classroom and lecture hall.

Further information on the structure and content of the Honors Program may be obtained by contacting the Office of the Dean of the College of Science.

The Environmental Research Center (UNDERC), a University facility, is composed of approximately 7,500 acres located primarily in the Upper Peninsula of Michigan. Research is conducted at UNDERC by undergraduate as well as graduate students on a variety of environmental problems, including the manipulation of ecosystems. Internships are available to support student participation in BIOS 569 at UNDERC each semester.

International Studies Program. Students from any of the majors in the College of Science may participate in one of the University of Notre Dame’s international study programs. Science students who go abroad generally do so in one of the two semesters of their junior year. Science students interested in international studies should discuss their plans with their advisor and with the associate dean, 248 Nieuwland Science Hall. Further information can be obtained through the International Study Programs office, 109 Hurley Hall.
Programs of Study

BIOLOGICAL SCIENCES

Program of Studies. The Department of Biological Sciences offers programs of study leading to the degrees of bachelor of science with a major in biological sciences or bachelor of science with a major in environmental sciences, master of science in biological sciences and doctor of philosophy. Also offered is a second major in environmental sciences for students in the College of Arts and Letters or in the College of Business Administration.

Program in Biological Sciences. The biological sciences encompass all aspects of microbial, plant and animal life. They include the biochemistry, genetics, development, physiology, evolution and ecology of all living things. Every educated person must have sound knowledge of the fundamental principles and facts of the biological sciences in order to understand himself or herself and the world in which he or she lives. In addition biologists, through their research, contribute to the development of theories and methods required for the solution of humanity’s problems in the fields of health, agriculture, industry and the preservation of the environment.

An undergraduate major in biological sciences prepares a student for graduate study (M.S., Ph.D., M.D./Ph.D.) leading to a research career, and also for admission to medical, veterinary and other professional schools. Graduates with a bachelor’s degree may enter careers in industry, government or health-related research laboratories. Those who wish to teach at the elementary or secondary level should also consider graduate training.

The goal of the Department of Biological Sciences is to educate its majors first as scientists prepared for the challenges of modern biology and second for any specialty area(s) in which they develop an interest, especially if that interest is directed toward graduate school and research. Also, for the approximately 60 percent of biology majors who initially express an interest in going to medical school or other health-related graduate programs, the key topic areas of modern biology emphasized in the core curriculum are also very relevant to their training as “medical” biologists.

Students majoring in biological sciences are required to follow a core curriculum. This core not only provides exposure to most areas of modern biology but also includes courses representative of all the levels of biological organization, i.e., from atoms and molecules through ecosystems. Students unsure of which area of biology most appeals to their interests will more easily arrive at that decision through the completion of the core.

Policy Statement on the Use of Organisms in Biological Sciences Teaching Laboratories. Some laboratory courses offered by the Department of Biological Sciences may involve the use of living or preserved organisms. Instructors use these animal specimens in cases where this is deemed necessary for teaching important biological concepts and principles. Students who have concerns about the use of animals in classes must, prior to registering, submit a request for alternate materials to the course instructor. It is up to the discretion of the instructor(s) as to whether and how non-organism alternatives may be substituted for biological materials in classes. Students permitted to use alternate materials are responsible for the same knowledge and application as their classmates and may be required to complete examinations that involve the inspection or handling of biological specimens.

BACHELOR OF SCIENCE WITH A MAJOR IN BIOLOGICAL SCIENCES

The biological sciences majors take the following basic sequence of courses in the College of Science:

General Chemistry (CHEM 113–114 or 117–118 or 125–126)
Organic Chemistry (CHEM 247-248 and 247L-248L)
Physics (PHYS 221-222)
Calculus (MATH 119–120 or 125–126)

Science elective (a three-or-more-credit science-major course, other than a biological sciences course)

The requirements in biological sciences include courses from a basic core sequence and sufficient numbers of BIOS electives to complete the 41-credit-hour requirement. There are seven components to the biology core requirement, consisting of courses in the following areas:

Core I: Introductory Biology
a. Metabolism and Genetics
b. Ecology, Diversity, and Physiology

Students choose from either:
• Biological Sciences I and II (BIOS 161–162) (includes two labs)
• General Biology A and B (BIOS 201-202) (includes two labs)

Core II: Cellular, Genetic and Molecular Biology
a. Modern Genetics

Students choose from either:
• Classical and Molecular Genetics (BIOS 250 and 250 L1)
• Fundamentals of Genetics (BIOS 303 and 303L)

b. Cell Biology

Students choose from either:
• Molecular Cell Biology (Majors) (BIOS 241 and either 241R or 341L)
• Cellular Biology (BIOS 341 and 341L)
SUMMARY OF REQUIREMENTS FOR GRADUATION FOR ANY BIOLOGICAL SCIENCES MAJOR

<table>
<thead>
<tr>
<th>Course Area</th>
<th>Courses</th>
<th>Credits</th>
<th>Year Usually Taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological Sciences*</td>
<td>41</td>
<td>all</td>
<td></td>
</tr>
<tr>
<td>Chemistry (113–114 or 117–118 or 125–126) and 247-248 with labs</td>
<td>10</td>
<td>Sophomore</td>
<td></td>
</tr>
<tr>
<td>Physics (221–222, or 131–132 or 151–152)</td>
<td>8</td>
<td>Junior</td>
<td></td>
</tr>
<tr>
<td>Mathematics (119–120 or 125–126)</td>
<td>8</td>
<td>First year</td>
<td></td>
</tr>
<tr>
<td>Science Elective (cannot be BIOS)</td>
<td>3</td>
<td>Junior/Senior</td>
<td></td>
</tr>
<tr>
<td><strong>Total Science:</strong></td>
<td><strong>78</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>History**</td>
<td>3</td>
<td>First year</td>
<td></td>
</tr>
<tr>
<td>Social Science**</td>
<td>3</td>
<td>First year</td>
<td></td>
</tr>
<tr>
<td>Philosophy**</td>
<td>6</td>
<td>Sophomore/Junior</td>
<td></td>
</tr>
<tr>
<td>Theology**</td>
<td>6</td>
<td>Sophomore/Junior</td>
<td></td>
</tr>
<tr>
<td>FYC 110</td>
<td>3</td>
<td>First year</td>
<td></td>
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<tr>
<td>Language Intermediate Level Competency</td>
<td></td>
<td>Sophomore/Junior</td>
<td></td>
</tr>
<tr>
<td>Literature/Fine Arts**</td>
<td>3</td>
<td>Junior/Senior</td>
<td></td>
</tr>
<tr>
<td>Free Electives</td>
<td>13+</td>
<td>Sophomore/Senior</td>
<td></td>
</tr>
<tr>
<td>Physical Education or ROTC (2 semesters)</td>
<td>0</td>
<td>First year</td>
<td></td>
</tr>
<tr>
<td><strong>124 credits</strong></td>
<td></td>
<td></td>
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</tbody>
</table>

* It is essential for prospective biology majors to begin their general biology courses in the first year in order to schedule all required core curriculum courses within a four-year period.

** One of these courses must be a University Seminar.

+ Minimum number of free electives based on the assumption that intermediate-level competency in language was achieved by taking three-credit courses.

Majors with AP course credits and/or language Credit by Exam (CE) often have time to incorporate 20 or more free elective credits (i.e., a second major or minor) into their four-year course selection.

Core III: Ecology
Students choose from either:
- General Ecology (BIOS 312) (includes lab) or
- Aquatic Ecology (BIOS 420) (includes lab)
If both ecology courses are taken, the second counts as the Core VI course (below).

Core IV: Developmental Biology
Students choose from either:
- Developmental Biology (BIOS 342; optional lab BIOS 342L) or
- Experimental Animal Development (BIOS 414) (includes lab)

Core V: Physiology
Students choose from either:
- Vertebrate (Human) Physiology (BIOS 344; optional lab BIOS 344L) or
- Integrative Comparative Physiology (BIOS 421; optional lab BIOS 421L)

Core VI: Evolution and Organismal Biology
Students choose among:
- General Botany (BIOS 304) (includes lab)
- Evolution (BIOS 305)
- The History of Life (BIOS 310)
- Plant Science (BIOS 325)
- Vertebrate Biology (BIOS 404)
- Plant Science (BIOS 325)
- General Entomology (BIOS 406; optional lab BIOS 406L)
- Animal Behavior (BIOS 407)
- A second ecology and other new courses, including 500-level graduate courses, as developed for Core VI or so designated by the department

Core VII: Microbiology and Infectious Disease
Students choose among:
- Principles of Microbiology (BIOS 401; optional lab BIOS 401L)
- Arthropods and Human Diseases (BIOS 408; optional lab BIOS 408L)
- Medical and Veterinary Parasitology (BIOS 415; optional lab BIOS 415L)
- Virology (BIOS 416)
- Immunology (BIOS 419)
- Epidemiology (BIOS 427)
- Cellular and Molecular Basis of Human Disease (BIOS 435)
- AIDS (BIOS 440) and other new courses, including 500-level graduate courses, as developed for Core VII or so designated by the department

Students are required to take a total of six laboratories; five of the six labs will be part of the Core (Core I(a,b), II(a,b), and III), and the sixth laboratory must be chosen from Core areas IV to VII. The minimum required credits in the core including labs is 33. An additional eight credits of electives in biological sciences are chosen to complete the required total of 41 credits.* All biological sciences majors are encouraged to include non-science among their “free electives.”

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* It is essential for prospective biology majors to begin their general biology courses in the first year in order to schedule all required core curriculum courses within a four-year period.

** One of these courses must be a University Seminar.

+ Minimum number of free electives based on the assumption that intermediate-level competency in language was achieved by taking three-credit courses.

Majors with AP course credits and/or language Credit by Exam (CE) often have time to incorporate 20 or more free elective credits (i.e., a second major or minor) into their four-year course selection.
Notes:
1. All first-year majors completing BIOS 161–162, or those enrolling in BIOS 201, are required to select the sequence CHEM 247-248 and its labs. This is especially important for career-oriented majors in biological sciences. Only those students changing their majors to biological sciences while enrolled in CHEM 223 or 224 would complete this alternative sequence. Students may not switch from CHEM 223 to CHEM 248 to complete the organic chemistry sequence.
2. Alternatively, students may select the physics sequences PHYS 131–132 or PHYS 151–152.
3. Any non-BIOS major-level College of Science courses (i.e., those taken to meet science-major requirements and not those designated as “Recommended University electives”) and that are not being used to fulfill other specific graduation requirements can be used to satisfy the “Science Elective” requirement (one three-credit hour course).
4. All majors are strongly encouraged to complete the sequence Biological Sciences I and II (BIOS 161–162) in their first year to ensure the completion of all requirements in four years. Students may begin the core with General Biology A and B (BIOS 201–202); however, they will be at a considerable disadvantage in scheduling requirements in the two remaining years; they also will have one year less to explore their interests in biology.
5. Career-oriented majors in biological sciences, as well as those considering a professional school (medicine, veterinary science, others), are urged to select the courses Molecular Cell Biology (BIOS 241) and Classical and Molecular Genetics (BIOS 250). These should be taken in the sophomore year but no later than the junior year.
6. Physiology should be completed by the end of the junior year for students planning to take the MCAT exam or the seventh semester for students planning to take the GRE biology subject exam.
7. Most graduate (500-level) courses (through 579) count toward the 41-credit biological sciences requirement; however, only a maximum of two credits per semester per course and a combined total of six credits from all of these three courses may be counted in fulfilling the 41-credit requirement. A maximum of only nine credits in these three courses may be used toward graduation; however, additional credits do remain on a student’s permanent transcript record.

RECOMMENDED COURSE GROUPINGS

After consultation with the director of undergraduate studies or other faculty advisors including research mentors, each student is encouraged to select the curriculum which best fits his or her career goals. A great deal of flexibility is permitted in designing each individual’s projected course schedule, within the context of the core curriculum. For students wishing to emphasize specific areas of biology in their curricula, the following four course groupings are provided as guides that have proved to be appropriate for most of our previous graduates.

General Biosciences: This grouping gives the student a broad foundation in biological sciences by requiring electives from each of its major areas. This grouping is designed as preparation for the Graduate Record Examination (GRE) in biology, or the Medical College Admission Test (MCAT). Students considering graduate school or secondary science education, or those without a clear career goal, should consider these courses.

Here, students follow the core curriculum, making choices in areas I to V and VII. In the area of Core VI, the course Evolution (BIOS 305) or the course The History of Life (BIOS 310) are recommended. Also recommended for electives in biological sciences is a course in either vertebrate or invertebrate biology (e.g., BIOS 404, Vertebrate Biology, or BIOS 406, General Entomology). Dependent on the credits associated with the choice of courses made in the core, students will generally be required to pick one to two more electives in biological sciences to complete the requirement of 41 credits.

Cellular and Subcellular: This grouping was designed for students considering graduate study in any of the many areas of cellular biology and biochemistry. It is also appropriate for premedical students who do not choose the general biosciences grouping.

For this grouping, students follow the core curriculum, making choices in areas I to IV and VI. In the area of Core V, Physiology, students should consider taking both courses listed. In the area of Core VII, the courses Introduction to Microbiology (BIOS 401) and Virology (BIOS 416) are recommended. For electives in biological sciences, a course in Immunology (BIOS 419), Genetics (BIOS 423), or Advanced Cell Biology (BIOS 539) is recommended. Molecular Genetics (BIOS 418) is also recommended as an elective. Dependent on the credits associated with the choice of courses made in the core, students will generally be required to pick one or more electives in biological sciences to complete the requirement of 41 credits.

Organismal Community: This grouping is primarily intended for students planning careers in ecology, environmental biology and related areas and allows students to develop considerable expertise during their undergraduate years. It requires electives in biological sciences beyond the 41 credits required of the major. Individual interests may be accommodated by judicious choice of biological science courses and of the science elective.

Students interested in this area of biological sciences may wish to take advantage of the University of Notre Dame Environmental Research Center (UNDERC), a University facility which comprises about 7,000 acres, including more than 20 lakes, in the Upper Peninsula of Michigan. Biological research (including whole-ecosystem experiments), graduate studies and undergraduate course work take place at the center. Paid internships are available to support student participation in BIOS 569 at UNDERC each summer.

In this grouping, students follow the core curriculum, making choices in areas I, II, IV, V, and VII. In the area of Core III, Ecology, students should consider taking both courses listed. In the area of Core VI, students are encouraged to take General Botany (BIOS 304) or Plant Science (BIOS 325). Also recommended from Core VI are Vertebrate Biology (BIOS 404) and/or General Entomology (BIOS 406) and Animal Behavior (BIOS 407).

Microbiology and Infectious Disease: This grouping is intended for students interested in microbiology and molecular biology and who are considering graduate study in these areas. It is also appropriate for premedical students. It requires electives in biological sciences beyond the 41 credits required of the major.

Here, students follow the core curriculum, making choices in areas I to VI. In the area of Core VII, students should take Principles of Microbiology (BIOS 401 and the lab BIOS 401L); Virology (BIOS 416); or Medical and Veterinary Parasitology (BIOS 415); Immunology (BIOS 419); Cellular and Molecular Basis of Human Disease (BIOS 435); and Epidemiology (BIOS 427) and/or A.L.D.S (BIOS 440).
Sample Curriculum: The sample curriculum for the four-year program listed below is only one of a number of ways a student can complete all the requirements for a biology major. Students should discuss their specific interests with their departmental advisor and plan their semesters accordingly. Alternative sample curricula can be developed with the assistance of the biology advisor.

Note that this sample curriculum assumes that no AP or language CE credits are included.

First Year
Fall Semester
BIOS 161 (Core Ia: Principles) 4
MATH 120 or 126 4
CHEM 113, 113L or 117, 117L 4
History or Sociology 3
Theology or Philosophy 3
Physical Education or ROTC 0

18

Spring Semester
BIOS 162 (Core Ib: Principles) 4
MATH 120 or 126 4
CHEM 114, 114L or 118, 118L 4
History or Sociology 3
Theology or Philosophy 3
Physical Education or ROTC 0

18

Sophomore Year
Fall Semester
BIOS 250 (Core Ila: Genetics) 5
CHEM 247, 247L 5
Theology/Philosophy 3
Language 3

16

Spring Semester
BIOS 241 (Core IIb: Cell Biology) 4
CHEM 248, 248L 5
Theology/Philosophy 3
Language 3

15

Junior Year
Fall Semester (overseas study is an option)
BIOS Core III (Ecology) 4
Physics 221, 221L 4
Free Elective 3
Theology/Philosophy 3
Language 3

17

Spring Semester
BIOS Core IV (Developmental Biology) 4
BIOS Core V (Comp. Physiology) 5
Physics 222, 222L 4
Fine Art/Literature 3

16

Senior Year
Fall Semester
BIOS Core VI (Evolution/Organismal Biology) 3
BIOS Core VII (Microbiology/Infectious Diseases) 3/4
BIOS/Science Elective 3
Free Elective 3

12/13

Spring Semester
BIOS VI or VII 3/4
BIOS/Science Elective 3
Free Elective 3
Free Elective 3

12/13

TOTAL: 124 minimum

1 One of these courses must be University Seminar 180.
2 Students declaring a biology major during the fall semester of their sophomore or junior year while taking organic chemistry (CHEM 223/223L) must complete the sequence with CHEM 224/224L. For all other biology majors, CHEM 247/247L and CHEM 248/248L are required courses. In special circumstances, with the permission of the director of undergraduate studies in biological sciences, students may receive permission to satisfy the organic chemistry requirement by taking CHEM 223/223L and/or CHEM 224/224L during Notre Dame’s summer session.
3 Offered spring semester also.
4 For premedical students, it is strongly recommended that the student take a 300-level English literature course. This ensures that the student will be able to meet the standard medical-school admission requirement of two English courses. Medical ethics and biochemistry are also generally required.
5 A BIOS/Science elective can be any 300-500 level biology course, not counted as part of the Biology Core Curriculum or any science-major course, other than those required, and approved by the director of undergraduate studies for the Department of Biological Sciences.
6 Same as above, but must be a non-biology course. Biochemistry (e.g., CHEM 420) is especially recommended.

In addition to the undergraduate curriculum, the Department of Biological Sciences offers programs of graduate study leading to the degrees of master of science and doctor of philosophy, as described in the Graduate School Bulletin of Information.

BIOLOGICAL SCIENCES COURSE DESCRIPTIONS

Course descriptions. The following course descriptions give the number and title of each course. The courses listed below are those reasonably expected to be offered several times to every semester during the next four years. However, changes may occur as faculty add new courses or drop those with little demand. Courses without laboratories are indicated as lecture only. The first number in parentheses indicates lecture hours; the second indicates laboratory hours; the third indicates total credits for the course.

Biology Survey Courses (101–117)
Prerequisite: One year of high school chemistry and biology. For first-year students only. These courses are designed for non-science majors and will address fundamental aspects of modern biology. There will generally be six sections of biology survey courses available each year; any course may have multiple sections. The listed courses (and new courses) are offered when demand warrants it, allowing subject matter to change depending on students’ interests and needs and emerging or changing areas of life science. These courses generally are Recommended University Electives and are not open to science majors.

These 100-level survey courses satisfy the science requirement for non-science majors at Notre Dame. They do not satisfy the science requirements for science majors at Notre Dame or elsewhere. Students may not take both BIOS 101 and 110 for degree credit because of the similarity in lecture material.

101. Human Genetics, Evolution, and Society
(3-0-3) Bender
This course will address fundamental biological principles using the two cornerstones of modern biology: genetics and evolution. Elementary chemistry, cell theory, reproduction and development will also be covered. The emphasis, however, will be on human genetics and will include such topics as the cause and effects of genetic abnormalities, the genetic basis of intelligence and skin color, genes and cancer and elementary population genetics. The state of “genetic engineering” research, the recombinant DNA controversy (including the implications of this kind of research on society and the individual) will be presented. Fall and spring.

106. Common Human Diseases
(3-0-3) Staff
The goal of this course is to introduce students to diseases that may afflict them, their parents and/or their children, as well as other health problems common to the tropics. It will provide the student with the information necessary to understand the biology of the disease process. Fall. Students may not take this course and the course SCPP 102.
107. Environment and Evolution
(3-0-3) Staff
Emphasis will be placed upon today’s ecological and environmental problems and the possible effect they may have upon the future evolution of life on Earth. Topics will generally include an overview of the theory of evolution and a discussion of ecological principles as observed at the population, community and ecosystem levels. The influence of cultural and political factors will also be discussed. Each academic year, one or more sections will be offered; some may be individually subdivided, allowing for one-time presentation of specific topics within the context of “environment and evolution” in addition to multiple-semester presentations of a specific topic (e.g., Evolutionary Ecology, Freshwater and Society, Wild-life Biology, Environmental Issues and Solutions). Fall and spring.

108. Revolutions in Biology
(5-0-3) Diffley
The goal of this course is to teach six basic tenets of biology, the historical context for each discovery, the scientific and technical advances made and their ethical implications. The topics will include genetics and evolution, cell biology and biochemistry, the germ theory, and ecology. A term paper is required. Summer.

109. Human Reproduction and Society
(3-0-3) Staff
Basic aspects of human development and reproduction will be covered from conception through sexual senescence. In addition, the science behind many currently debated social issues will be addressed. Selected topics might include causes and treatment of infertility, in vitro fertilization, control of male and female fertility, pregnancy and paternal testing, gene therapy, the effects of legal and illegal drug use on reproductive function and embryonic/fetal development, and the impact of current health care policy and practice on infant and prenatal health. Fall. On demand.

110. Genetics, Technology, and Society
(3-0-3) Whaley
The objectives of this course are to give students an overview of human genetics and an appreciation for the relatively new field of molecular biology that is currently being used to study human genetic diseases. Genetic technologies such as cloning and manipulating genes, genetic biotechnology, gene therapy, DNA testing and so forth will be emphasized. The ethical, social and legal implications of these technologies will also be covered. In addition, this course will address the role of genetics in human cancer, behavior, obesity, intelligence and sexual orientation. Summer.

116. Biology and Nutrition
(3-0-3) Staff
This course provides a general overview of the field in nutrition. Topics to be presented include an introduction to the field of nutrition, nutrient composition of foods, recommended intakes and health claims, a review of the nutrients, food intake and energy balance, sports nutrition, eating disorders, current issues of food safety, fads, and other aspects encompassing nutrition during all stages of life. On demand.

117. Biodiversity: Its Challenge and Future
(3-0-3) Staff
Today, species of plants and animals are going extinct at an unprecedented rate in the 3.5 billion year history of life on Earth. Not only are species going extinct, but complete assemblages of species in particular habitats are threatened. The class will survey the reasons why this disappearance of species and habitats concerns biologists, the basic concepts that biologists hope to employ to help prevent the continuance of this trend, and the problems faced in formulating policies that address this problem. This human problem is important locally and globally, since legislation attempting to halt the loss of biological diversity will affect the actions of people at the community, state, national and international levels. To the majority of people in the USA and other developed countries, concern for biodiversity is second only their economic well-being. On demand.

**BIOLOGY MAJORS COURSES (161–498)**

161–162. Biological Sciences I and II
(3-3-4) Belovsky, Shay, Olsen
Prerequisites: High school biology and chemistry. BIOS 161L, 162L, AND CHEM 113–114 OR 117–118 are to be taken concurrently. BIOS 161-162 are the prerequisites for BIOS 162, 162L. Restricted to biology and biochemistry intent/majors. Note: BIOS 161–162 is the replacement for BIOS 155–162.

This is a two-semester course with three lectures and one three-hour laboratory a week for first-year students contemplating a career in biology, medicine or related areas of life science.

The first semester presents a description of biologically important molecules and then proceeds to cell structure, energy metabolism and classical and modern genetics. The topics presented in the second semester in the context of modern evolutionary theory include biological diversity, ecology and organismal physiology.

BIOS 161 and 162 are not typical survey courses; they go into greater depth, especially in modern molecular biology. When followed by BIOS 241 and BIOS 250 they will provide biology and biochemistry majors, including pre medical intents, with a thorough in-depth overview of basic concepts of modern biology.

The laboratory sessions are an integral part of the lecture courses, which will complement the lectures. In addition, students learn to present their findings as they would for a journal article or a scientific meeting (seminar and poster presentations). The lab sessions will offer the student direct experience in using the scientific method and simultaneously provide an introduction to numerous biological and analytical techniques.

Note: Students are not allowed to switch from the 201–202 sequence to the 161–162 sequence. BIOS 201 must be completed before BIOS 202 is taken; similarly, BIOS 161 must be finished before BIOS 162 is taken. In some instances, students who started with BIOS 161 will be allowed to finish the basic biology sequence with the course BIOS 202. While this is allowed, a student should not plan this as an option. Note that both BIOS 161 and 202 are fall courses; thus, for students changing between first- and second-year sequences, BIOS 161 would have been taken in the fall of the first year along with general chemistry, and BIOS 202 would need to be taken in the spring of the sophomore year after completion of general chemistry.

191. Molecular Genetic Technology
(3-0-3) Whaley
Open to non-science honors students only. Not available to students who have previously taken BIOS 101 or BIOS 110.

The objectives of the course are to have students learn the basics of cell division and Mendelian genetics and then explore the relatively new field of DNA technologies such as gene cloning, genetic testing, biotechnology, and cancer genetic analysis. This course also has a service learning component in which students will work at the Logan Center in South Bend. Fall.

201–202. General Biology A and B
(3-0-3) Tenniswood, Hellenthal, Filchak
Prerequisites: CHEM 114 or 118 or 126.
Introduction to living organisms with emphasis on biological processes and principles.

BIOS 201 and 202, along with their concomitant laboratories (BIOS 201L and 202L) constitute a traditional two-semester introduction to biology. This sequence covers more topics, but in less depth, than BIOS 161 and 162 and is designed to provide students with the necessary background for subsequent advanced biology courses and to help them prepare for MCATS. A prerequisite is a full year of college chemistry. In addition, organic chemistry is to be taken concurrently. BIOS 201 introduces biology to the student at the cellular level, covering such topics as important biological molecules, energy metabolism, and classical and modern genetics. BIOS 202 goes beyond the cellular level, with an emphasis on organismic physiology, evolution, diversity and ecology.

Note: CHEM 114 or 118 or 126 must be completed before taking BIOS 201. BIOS 201, 201L, and 202, 202L may be substituted for 161–162; however, this sequence is quite different from 161–162 in content and does not provide the depth afforded by 161–162 nor does 201–202 provide the equivalent laboratory experience essential to biology majors intent on taking BIOS 241 and 250.
201L–202L. General Biology Laboratory
(0-3-1) (0-3-1) Lewis
Students registering for 201–202 must concurrently register for 201L–202L respectively.

241. Molecular Cell Biology
(3-0-3) Staff
Prerequisites: BIOS 161, 250, 250L.
Prerequisites or Corequisites: BIOS 241L and CHEM 248 and 248L.
This course is restricted to biological science and biochemistry majors only. This course explores the fundamental structural and functional basis of cell biology, with specific emphasis on molecular mechanisms that regulate cellular activities involved in ion and solute transport, organelle biogenesis, protein trafficking and vesicular transport, intracellular communication and signalling, cell cycle growth control regulation, and cytomechanics. The lecture portion of the course is dedicated to exposing students to the protein machinery driving cell functions, while the laboratory complements lecture by providing a combination of experiments and opportunities for independent project-based investigation focused on elucidating basic cell function. Spring.

241L. Molecular Cell Biology Laboratory
(0-3-1) Whaley
Prerequisite or Corequisite: BIOS 241, BCHM majors only
This cell biology laboratory exposes students to a variety of techniques in modern cell biology. It is designed expressly for BCHM majors; the laboratory techniques are not as extensive as the BIOS 241R two credit laboratory for BIOS majors, since BCHM majors gain similar experience in one of their required laboratory courses. Spring.

241R. Research Experience in Cell Biology
(0-4-2) Whaley
Prerequisite or Corequisite: BIOS 241, BIOS majors only
This cell biology laboratory is an investigative, project-based laboratory designed to expose students to a bona fide research experience involving the development and application of critical thinking skills to solve complex research problems. Working in groups of four to six, students will devote themselves to tackling self-chosen research projects reviewed and approved by course instructors. The culmination of the laboratory experience ends when students formally prepare and present their findings in a poster-style scientific meeting. Spring.

250. Classical and Molecular Genetics
(3-0-3) Hyde
Prerequisite: BIOS 161.
Prerequisite or Corequisite: CHEM 247 and 247L.
This course is restricted to biological science and biochemistry majors only. The course exposes students to classical and molecular genetics and demonstrates how these two approaches can combine to examine complex problems. The lecture is strongly weighted toward teaching students to solve genetic and molecular biological problems. Classical genetic principles are introduced first. Students are then presented with the techniques to examine underlying genetic principles through problem solving. Basic principles and techniques of molecular biology are next presented, and students learn how to apply these techniques to explore genetic problems. The laboratory gives the students hands-on experience in a number of genetic and molecular techniques and demonstrates how these procedures are combined to produce a cohesive genetic picture. Experiments begin with classical genetic analysis of a mutation, progress to isolating the mutant gene by PCR and standard cloning techniques, followed by DNA sequencing the genomic fragments to determine the nature of the genetic defect. Immunolocalization of the protein in mutant and wild-type flies brings the molecular work back to the organism, providing a full-circle study of the genetic mutation under study. At the end of the lab, students are ready for the independent study projects conducted in the laboratory for BIOS 241, Molecular Cell Biology. Fall.

250L. Classical and Molecular Genetics Laboratory
(0-3-1) Whaley
Corequisite: BIOS 250.
In this laboratory course, students will characterize mutations that cause retinal degeneration in the fruit fly, Drosophila melanogaster, in a series of related experiments comprising a semester-long study. The labs will be broken into two major sections, starting with the genetic characterization of a mutation, followed by the molecular characterization of the altered gene causing that mutation. This directed research project will be presented in two drafts of a complex research paper. Some work outside the three-hour lab period will be required. Fall.

294. Neotropical Natural History
(V-V-3) Hamlet
Prerequisites: Permission of the instructor and BIOS 162 or 202 with labs.
This course will be a summer offering for three credit hours; science majors may take it only as a free general elective. Topics will be presented as lectures, videotapes, slide programs and reading assignments. There will be a written examination after the first two weeks, prior to the field laboratory portion of the course. The next two weeks of the course will be held in the field in Belize and Guatemala. A daily journal will be kept by each student. A series of four to five question sets based on different portions of the trip will be turned in and graded. Following the field portion of the course, there will be post-field-trip lectures and discussion on campus. In consultation with the course instructor, each student will prepare a research paper and be given a final examination on field material and text assignments. Students will pay tuition as well as additional costs sufficient to cover their expenses while in Central America. The course will provide a broad coverage of the biology of the flora and fauna of Central America and an introduction to efforts being made to preserve and manage the natural resources of this area. The students will have an opportunity to experience the habitats and see the plants and animals firsthand. We will visit selected nature preserves, virgin rain forest, tropical savannas and the second largest coral reef in the world. Topics covered will include tropical ecosystems, rain forests and how they function, tropical plants, rain forest fauna, and tropical savannas, as well as Mayan civilization, history and how they utilized and sustained their natural habitat; Maya today in relation to resource management; coastal ecosystems of mangroves, seagrass and coral reef; marine fauna and flora; neotropical resource management; and ecotourism. Summer (irregular offering).

303. Fundamentals of Genetics
(3-0-3) Besansky/Severson
Prerequisite: BIOS 161 or 201.
An elementary course dealing with the principles of variation and inheritance in plants and animals, with special reference to humans. Designed primarily for junior preprofessional students. Spring.

303L. Genetics Laboratory
(0-3-1) Besansky/Severson
Prerequisite or Corequisite: BIOS 303.
Laboratory provides experience in genetic experimentation and analysis. Required for biology majors, optional for others. Spring.

304. General Botany
(3-3-4) Staff
Prerequisite: BIOS 162 or 202.
A broad survey of the plant kingdom, emphasizing morphology and anatomy, with attention given to major plant functions of growth and development in chiefly angiospermous (= “higher”) plants. Laboratory instruction includes a semester project involving photomicrography or seed germination and cloning.
305. Evolution  
(3-0-3) Hollocher  
Prerequisite: BIOS 162 or 202.  
The mechanisms and processes involved in the production of life as we know it today, as well as a discussion on the impact current events may have upon life in the future. Spring.

310. The History of Life  
(3-0-3) Feder  
Prerequisites: BIOS 162 or 202.  
This course explores the origin, history, and systematics of life on Earth, starting from hypotheses examining life’s origin(s) and including current thinking concerning the systematic relationships of organisms and the evolution of humans. The class will be taught primarily from a macroevolutionary perspective. BIOS 310 therefore represents the complement to BIOS 305 (Evolution), which concentrates on processes generating gene frequency changes within populations (i.e., microevolution). Fall.

312. General Ecology  
(3-3-4) Staff  
Prerequisite: BIOS 162 or 202.  
The study of populations and communities of organisms and their interrelations with the environment. Fall and spring.

325. Plant Science  
(3-0-3) Romero-Severon  
Prerequisites: BIOS 250 or 303 and BIOS 241 or 341  
This course will provide an introduction to plant biology, biochemistry and ecology. Specific topics include plant development, photosynthesis, nitrogen fixation, grassland and forest ecology, plant domestication and the ecological impact of plant domestication. The course will emphasize the unique aspects of plant biology and illustrate how plants sustain life on earth. Fall.

338. Neurobiology  
(3-0-3) Li  
Prerequisites: BIOS 241 or BIOS 341 and BIOS 250 or 303  
An introductory course emphasizing how the central nervous system controls our actions and behaviors. The material will cover topics ranging from single nerve cell function to neural circuitry. Students who are interested in pursuing either medical or life science related graduate or professional degrees are particularly encouraged to take this course. Fall.

341. Cellular Biology  
(3-0-3) Staff  
Prerequisites: BIOS 161 or 201; CHEM 223 or 247.  
Designed primarily for junior preprofessional students. Structural and functional aspects of the biology of cells are addressed. Fall and spring.

341L. Cell Biology Laboratory  
(0-3-1) Welsh  
Prerequisite or corequisite: BIOS 241 or 341.  
This laboratory course exposes students to a variety of techniques in modern cell biology. Students will get hands-on experience in working with cultured cell lines, including sterile technique, media preparation and passaging of cells. Individual experiments will include assessment of cell growth and apoptosis, examination of subcellular structure using fluorescent microscopy, separation and analysis of nucleic acids and proteins, enzyme assays and measurement of cell cycle by flow cytometry. It provides an excellent introduction to the approaches routinely used in analysis of cells and their functions. Fall.

342. Developmental Biology  
(3-0-3) Staff  
Prerequisite: BIOS 162 or 202.  
Development of plants, animals and microorganisms studied at the molecular, cellular and organismic levels. Spring.

342L. Developmental Biology Laboratory  
(0-3-3) Staff  
Prerequisite or Corequisite: BIOS 342.  
Laboratory exercises will examine the basic developmental mechanisms of animals and plants. On demand.  
Note: Students may not take both BIOS 342 and 414 because the lecture materials are very similar in these two developmental biology courses.

344. Vertebrate Physiology  
(3-0-3) Boyd  
Prerequisite: BIOS 162 or 202.  
Physiological functions and processes at the level of organs and organ systems, oriented primarily toward humans. Designed primarily for junior preprofessional students. Fall.

344L. Vertebrate (Human) Physiology Laboratory  
(0-3-1) Boyd  
Prerequisite or Corequisite: BIOS 344.  
Laboratory experience in physiology. Ideally, this laboratory is taken after students have completed the BIOS 344 lecture. Fall.

401. Principles of Microbiology  
(3-0-3) Kulpa  
Prerequisites: BIOS 162 or 202 and CHEM 224 or 248.  
An introduction to microbial life, including structure and function of bacteria. Characterization and classification of microorganisms are considered and include their ecology, growth and death, metabolism, physiology, genetics and antigenic analysis. The impact of microorganisms on human health is discussed through representative pathogenic bacteria. Fall.

401L. Principles of Microbiology Laboratory  
(0-3-1) Kulpa  
Prerequisite or Corequisite: BIOS 401.  
Laboratory exercises consider basic techniques in microbiology, such as sterile procedures and microbial metabolism. Fall.

404. Vertebrate Biology  
(3-0-3) Johnson  
Prerequisite: BIOS 162 or 202.  
A study of systematic relationships, evolution and life histories of living and extinct vertebrates, and the physiology and behavior of living vertebrates. Fall.

406. General Entomology  
(3-0-3) Collins  
Prerequisite: BIOS 162 or 202.  
A study of the morphology, life histories and systematic relationships of insects, with emphasis on medical and agricultural aspects. Alternating fall semesters.

406L. General Entomology Laboratory  
(0-3-1) Collins  
Prerequisite or Corequisite: BIOS 406.  
The laboratory introduces students to insect morphology, systematic and techniques used in the study of insects. Offered concurrently with lecture.

407. Animal Behavior  
(3-0-3) Esch  
Prerequisite: BIOS 162 or 202.  
A consideration of individual and social behavior patterns, with emphasis on organization and adaptive significance. Neural, endocrine, genetic and environmental factors modifying behavior will be examined. Spring.

408. Arthropods and Human Disease  
(3-0-3) Collins  
Prerequisite: BIOS 162 or 202.  
Emphasis on physiology, genetics and relationships of arthropods as agents and vectors of disease. Alternating spring semesters.

408L. Medical and Veterinary Entomology Laboratory  
(0-3-1) Collins  
Prerequisite or Corequisite: BIOS 408.  
The laboratory introduces students to the variety of arthropods that vector disease agents or otherwise affect the lives of humans and other vertebrate animals. Offered concurrently with lecture.

411. Biostatistics  
(3-1-4) Lamberti  
Prerequisites: BIOS 162 or 202; MATH 120, 126, 166 or 196.  
Basic principles of statistical analysis and their application to biological problems, including statistical inference, analysis of variance, regression, non-parametric approaches, and introduction to statistical computing. This course’s “lab” is a tutorial; it does not fulfill the laboratory elective requirement. Students may not take both BIOS 411 and MATH 214. Spring.
414. Experimental Animal Development  
(3-3-4) Staff  
Prerequisites: BIOS 241 or 341 and BIOS 250 or 303.  
Experimental approaches to the study of development. Emphasis is placed on molecular and genetic analyses of model systems: invertebrate, amphibian, avian and mammalian. Concurrent enrollment in the laboratory (BIOS 414L) is required. Since laboratory and lecture material are integrated throughout the semester, laboratory may not be taken separately from lecture. NOTE: Students may not take both BIOS 342 and 414 because the lecture materials are very similar in these two developmental biology courses. On demand.

415. Medical and Veterinary Parasitology  
(3-3-4) Adams  
Prerequisite: BIOS 161 or 202.  
The animal parasites of humans and related hosts are reviewed. The pathology caused by these parasites, epidemiology, life cycles, prophylactic and therapeutic control are considered. Spring.

415L. Medical and Veterinary Parasitology Laboratory  
(0-3-1) Adams  
The laboratory introduces students to the microscopic world of parasites. Extensive microscope work is needed. On demand.

416. Virology  
(3-0-3) Fraser  
Prerequisites: BIOS 162 or 202; and 241 or 341 and 250 or 303.  
A study of viruses as primitive biological entities and as disease-inducing agents in humans and other animals: characteristics of viruses and virus infections; molecular aspects of virus replication; methods for diagnosis and prevention of infections; artificial use of viruses. Spring.

417. Human Musculoskeletal Anatomy  
(3-0-3) O’Malley  
Prerequisite: BIOS 161 or 202.  
An introduction to basic anatomical principles relating to bones and muscles and to the normal anatomical and biochemical aspects of the human musculoskeletal system. Fall.

418. Molecular Genetics  
(3-0-3) Adams  
Prerequisites: BIOS 250 or 303 (genetics); a course in biochemistry would be useful.  
The course will introduce the tools of modern molecular biology and explore their applications at the frontiers of biological research. Advanced topics may include molecular medicine, biotechnology, development, evolution and neurobiology. Fall.

419. Immunology  
(3-0-3) McDowell  
Prerequisite: BIOS 250 or 303; BIOS 241 or 341.  
An introductory course emphasizing the cells and tissues of the immune system and the nature and function of antigens and antibodies. A survey is presented of immune capabilities of humans and animals, immune diseases, immunodeficiency states, transplantation of organs and the influence of nutrition on the immune system. Fall.

420. Aquatic Ecology  
(3-3-4) Hellenthal  
Prerequisites: BIOS 162 or 202.  
A study of the structure and function of aquatic systems with emphasis on the behavioral, physiological and morphological adaptations generated by the physical and chemical characteristics of various aquatic habitats. Fall.

421. Integrative Comparative Physiology  
(4-0-4) Johnson, Duman  
Prerequisite: BIOS 241.  
Designed primarily for students in the biology or biochemistry majors sequences. This course is designed to be taken either as an introductory animal physiology course for students without formal training in physiology beyond general biology or as a second physiology course for students who have already taken BIOS 344. General physiological principles are introduced, and the course is designed around the classical organs/system approach to physiology but with stress on comparative and evolutionary relationships. Emphasis is placed on the integrated nature of the various physiological systems and on the relationships of the physiology of the organism to its environment (physiological ecology) as well as to the lower levels of biological hierarchy (biochemistry, cell and molecular biology). Special emphasis is placed on adaptations to environmental extremes. This course has four lectures per week. Spring.

421L. Integrative Comparative Physiology Laboratory  
(0-3-1) Johnson, Duman  
Prerequisite or Corequisite: BIOS 421.  
Laboratory provides experience with experimentation and analysis of physiological concepts at the organismal, cellular and molecular levels. Spring.

423. Genomics: Sequence to Organism  
(3-0-3) Ferdig  
This course will introduce the methods of genome science and explore their applications in biological research and their impact on biological thinking. Topics will include how genomes are studied, how they function, and how they evolve. The importance of comparative functional genomics in identifying mechanisms of human diseases will be highlighted. Spring.

426. Fundamentals of Human Genetics  
(3-0-3) Bender  
Prerequisite: BIOS 250 or 303.  
Survey of methods utilized in human genetics studies as applied to medical, physiological and social problems. Spring.

427. Epidemiology  
(3-0-3) Grimstad  
Prerequisite: BIOS 162 or 202.  
A consideration of the natural history or ecology of diseases as they occur in humans and animals. This course is designed for upperclass students entering health-related fields. On demand.

435. Cellular and Molecular Basis of Human Disease  
(3-0-3) Schorey  
Prerequisites: BIOS 241 or 341; BIOS 250 or 303  
This course will explore the cellular and molecular mechanisms underlying various human diseases. Following an introduction to principles of disease, lectures will focus on recent advances in cellular and molecular aspects of immune responses and inflammation, pathogenic mechanisms and tumor cell biology (including abnormal growth regulation, invasion and metastasis). Specific examples of human diseases will be utilized to illustrate the concepts of disease-related gene products, the use of experimental animal models and the development of novel therapeutic strategies. Spring.

440. AIDS  
(3-0-3) Fraser  
Prerequisites: BIOS 250 or 303 and 241 or 341, including labs; BIOS 401 or the equivalent is also highly recommended.  
This course will explore the phenomenon of AIDS, including characteristics of the worldwide AIDS pandemic, the virus (HIV) itself, the immune system and HIV, methods of diagnosis, prevention, treatment and basic epidemiology as it relates to AIDS. This is an advanced course in infectious diseases designed for preprofessional and other interested students. Fall.

475. Laboratory Animal Science  
(2-0-2) Grimstad, Stewart  
Prerequisites or Corequisites: BIOS 162 or 202 and consent of instructor.  
An introduction to laboratory animal science, focusing on federally mandated regulations, animal rights/animal welfare controversies, general care and use of animals in a full-compliance program, and common methodologies used in animal-based research. Enrollment is by consent of instructor only and limited to junior or senior undergraduate prevetinary students, or biology majors whose graduate career program will require animal use, or graduate students whose research requires animal use at Notre Dame. Spring.
475L. Laboratory Animal Science Laboratory
(0-6-2) Stewart, Grimstad
Prerequisites: BIOS 475 and consent of instructor.
This course focuses on experimental techniques and methodologies in both laboratory and clinical settings. Students will divide their laboratory time between hands-on work in the animal facility and clinical experience in area veterinary clinics when possible. Enrollment is by consent of instructor only and limited to senior undergraduate preveterinary students, or senior biology majors whose graduate research program will require animal use at Notre Dame. Every student will be required to keep a complete notebook and develop a semester journal project or case study. Fall.

495. Teaching Practicum in Life Sciences
(0-4-2) Staff
Prerequisite: Permission of instructor.
This course gives the advanced student an opportunity to gain direct experience in teaching. Students are assigned regular teaching duties in certain laboratory courses and must be prepared to accept responsibility. Note: Most states will not accept this in lieu of practice teaching in an education department. Students must clear lab assignments with Kristin Lewis or other practicum coordinator. Fall and spring.

497. Directed Readings
(V-V-V) Staff
Prerequisite: Permission of instructor.
This course provides the opportunity for independent study through readings on specific topics in biological science. Readings are chosen with the advice of the supervising instructor. Students must register for more than three credits per semester; only two credits per semester may be counted as BIOS elective credits by majors. Offered all semesters.

498. Undergraduate Research
(V-V-V) Staff
Prerequisite: Permission of instructor.
Research in collaboration with members of the faculty. Evaluation of performance will be accomplished through regular discussions with the faculty member in charge of the course. Enrollment must be completed before the end of the first week each semester. Students may not register for more than three credits per semester; only two credits per semester may be counted as BIOS elective credits by majors. Offered all semesters.

The following undergraduate courses have been offered periodically as demand dictates:

102. Plants, Food, and Society
105. Parasitism, Disease, and Public Health
111. Biological Basis of Human Behavior
112. The Marine Environment
113. Understanding Virtues
114. Avian Biology
115. Microbes and Man
402. Microbial Physiology
403. Invertebrate Biology
409. Plant Taxonomy
413. Cytology
422. Marine Biology
424. Tumor Cell Biology
430. Advanced Animal Physiology
455. Infection and Immunity
460. Plant Ecology
462. Applied Environmental Microbiology
463. Aquatic Botany
464. Antibiotics and Chemotherapeutics

UNDERC Field Biology Program.
A special seven-credit program primarily for undergraduate students involving three semesters that emphasizes field biology is offered at the University's Environmental Research Center. Undergraduate students must apply to the program; only a limited number may be selected each year because of limited availability of space on site. On selection in late fall, students enroll in BIOS 598 for one credit and BIOS 569 for six credits. The summer's project is completed in the subsequent fall semester.

Required courses:
568. Introduction to UNDERC
(1-0-1) Belovsky
A seminar course preparing students for the BIOS 569 UNDERC experience. Spring.

569. Practicum in Aquatic Biology
(V-V-6) Belovsky
Practical training in aquatic and environmental biology is emphasized through lecture and field experience at the University's environmental research facility, located in the Upper Peninsula of Michigan. Course includes an independent research project.

SELECT GRADUATE-LEVEL COURSES

500-level courses in biological sciences are open to qualified undergraduates, subject to the approval of the course instructors and the director of undergraduate studies. Graduate-level courses that generally include a majority of upperclass students and that are recommended to undergraduate majors include:

501. Advanced Molecular Genetics
502. Genetics of Lower Eukaryotes
503. Advanced Microbial Physiology
504. Developmental Genetics
506. Cytogenetics
508. Population Genetics
509. Plant Anatomy
510. Experimental Parasitology
511. Protozoology
512. Helminthology
514. Field Parasitology
515. Vector Genetics
516. Physiological Chemistry of Animal Parasites
517. Biological Microtechnique
518. Cell Variation and Growth
520. Arbovirology
523. Practicum in Environmental Biology
524. Ichthyology
525. Community Ecology
526. Invertebrate Pathology
527. Stream Ecology
528. Environmental Microbiology
529. Theoretical Population Ecology
530. Immunobiology of Infectious Diseases
531. Molecular Biology I
532. Molecular Biology II
533. Proteins and Nucleic Acids
534. Plant Physiology
535. Comparative Endocrinology
536. Advanced Virology
537. Microbial Genetics
538. Neurobiology
539. Advanced Cell Biology I
540. Advanced Cell Biology II
541. Physical Chemistry for Biologists
543. Ethics and Science
554. Biological Research Applications of Computers
556. Histology
558. Biological Electron Microscopy
560. Environmental Physiology and Biochemistry
561. Advanced Aquatic Ecology
562. Aquatic Insects
563. Wetland Ecology
564. Behavioral Ecology
565. Nutrition
570–579. Topics Courses

The above 500-level courses are described in the Graduate School Bulletin of Information.
Program of Studies. Chemistry is the science of substances that comprise the world about us and is concerned with their structure, their properties and the reactions that change them into other substances. Chemists and biochemists practice their profession in many ways—in educational institutions, government laboratories, private research institutions and foundations and in many commercial areas, including the petroleum, chemical, drug, health, biotechnology, pharmaceutical and food industries.

The Department of Chemistry and Biochemistry has a strong undergraduate program together with a strong graduate education and research program. This graduate program greatly benefits undergraduate education by attracting highly qualified faculty and results in the availability of excellent research facilities and modern instrumentation necessary to train the scientists of tomorrow. This department is able to provide an excellent program of undergraduate research to complement regular course work. Student participation in research is highly encouraged as a key part of the education of chemistry and biochemistry majors.

The programs in chemistry and biochemistry described in the following pages prepare students for graduate studies and professional work in the chemical and biochemical sciences, as well as in interdisciplinary areas that rely heavily on chemistry. Bachelor of science degrees are offered with a major in chemistry, or a major in biochemistry. At the graduate level, the Department of Chemistry and Biochemistry offers programs leading to the degrees of master of science and doctor of philosophy, as described in the Graduate School Bulletin of Information.

BACHELOR OF SCIENCE WITH A MAJOR IN CHEMISTRY

The chemistry curriculum at Notre Dame includes two programs: the Chemistry Career Program, designed for students interested in a professional career in chemistry, and the Chemistry Combination Program, designed for those students who are interested in combining chemistry with business or with computing.

All chemistry majors take the following basic sequence of courses:

- General Chemistry (CHEM 125–126 recommended; or optionally, CHEM 113–114 or 117–118)
- Organic Chemistry (CHEM 235, 235L, 236, 236L)
- Physical Chemistry (CHEM 321, 321L, 322, 322L)
- Analytical Chemistry (CHEM 333, 333L)
- Physical Methods of Chemistry (CHEM 434)

Program Electives

- History
- Social Sciences
- Philosophy
- Theology
- Literature/Fine Arts

SUMMARY OF MINIMAL REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE IN CHEMISTRY AND BIOCHEMISTRY

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Language

- Intermediate Level Competency
  - FYC 110
  - Philosophy
  - Theology
  - Literature/Fine Arts
  - History
  - Social Sciences

Professors:

- Subhash C. Basu; Roger K. Brethhauer (emeritus); Richard W. Fessenden (emeritus); Jeremiah P. Freeman (emeritus); Robert G. Hayes (emeritus); Paul Helquist; Emil T. Hofman (emeritus); Paul W. Huber; Dennis C. Jacobs; A. Graham Lappin; John Magee (emeritus); Joseph P. Marino; Dan Meisel; Thomas L. Nowak; Robert H. Schuler (emeritus); Anthony Serianni; Slavi Sevov; Bradley D. Smith; J. Kerry Thomas (emeritus); Anthony M. Trozzolo (emeritus)

Associate Professors:

- Seth Brown; Gregory V. Hartland; Kenneth W. Henderson; Marya Lieberman; Maurice E. Schwartz (emeritus); Richard E. Taylor; Rev. Joseph L. Walter, C.S.C.; Olaf G. Wiest

Assistant Professors:

- Brian M. Baker; Eli J. Barkai; Jennifer DuBois; J. Daniel Gezelter; Holly V. Goodson; S. Alexander Kandel; Masaru Kenneth Kuno; Jeffrey W. Peng

In addition to this basic sequence, the following courses are required for each program.
### Chemistry Career Program

**Science Electives (six credit hours)**

**Combination Program**

Program Electives (15 credit hours)

Science Electives (three credit hours)

The program electives for the Chemistry Combination Program are from either the area of business or from the area of computing and are the same as those in the corresponding Collegiate Sequence programs:

**Chemistry with Business**
- Accounting and Accountancy I (ACCT 231)
- Accounting and Accountancy II (ACCT 232)
- Business Finance (FIN 231)
- Introduction to Management (MGT 231)
- Introduction to Marketing (MARK 231)
- Introduction to Economics (ECON 101 or 201)

is suggested, as a non-program elective, as a prerequisite to MARK 231 and meets the University social science requirement.

**Chemistry with Computing**
- Advanced Programming (CSE 232)
- Discrete Mathematics (CSE 210)
- Data Structures (CSE 331)
- Functional Programming (CSE 233) and Database Concepts (CSE 346)
- or Automata (CSE 411) and Algorithms (CSE 413)
- or Automata (CSE 411) and Compilers (CSE 443)

**Sample Curriculum (Career Program):**

#### First Year

**First Semester**
- CHEM 125 4
- MATH 125 4
- PHYS 131 4
- FYC 110 3
- History\(^a\) 3
- Physical Education/ROTC 0

**Second Semester**
- CHEM 126 4
- MATH 126 4
- PHYS 132 4
- Philosophy\(^a\) 3
- Social Science\(^a\) 3
- Physical Education/ROTC 0

**Sophomore Year**

**First Semester**
- CHEM 235 3
- CHEM 235L 1
- MATH 225 3.5
- PHYS 231 3.5
- Language 3

**Second Semester**
- CHEM 236 3
- CHEM 236L 2
- CHEM 243 3
- CHEM 202\(^a\) 1
- Language 3
- Theology\(^a\) 3

**Junior Year**

**First Semester**
- CHEM 321 3
- CHEM 321L 2
- MATH 225 3.5
- PHYS 231 3.5
- Language 3

**Second Semester**
- CHEM 326 3
- CHEM 326L 2
- CHEM 333 3
- CHEM 333L 2
- Philosophy 3
- Elective 3
- Theology\(^a\) 3

**Senior Year**

**First Semester**
- CHEM 420 3
- CHEM 443 3
- Elective 3
- Fine Arts or Literature 3

**Second Semester**
- CHEM 423 3
- CHEM 434 3
- Elective 3
- Elective 3

**Sample Curriculum (Combination Program):**

#### First Year

**First Semester**
- CHEM 125 4
- MATH 125 4
- PHYS 131 4
- FYC 110 3
- History\(^a\) 3
- Physical Education/ROTC 0

**Second Semester**
- CHEM 126 4
- MATH 126 4
- PHYS 132 4
- Philosophy\(^a\) 3
- Social Science\(^a\) 3
- Physical Education/ROTC 0

**Sophomore Year**

**First Semester**
- CHEM 235 3
- CHEM 235L 1
- MATH 225 3.5
- PHYS 231 3.5
- Language 3

**Second Semester**
- CHEM 236 3
- CHEM 236L 2
- CHEM 243 3
- CHEM 202\(^a\) 1
- Language 3
- Theology\(^a\) 3

**Junior Year**

**First Semester**
- CHEM 321 3
- CHEM 321L 2
- MATH 225 3.5
- PHYS 231 3.5
- Language 3

**Second Semester**
- CHEM 326 3
- CHEM 326L 2
- CHEM 333 3
- CHEM 333L 2
- Philosophy 3
- Elective 3

**Senior Year**

**First Semester**
- CHEM 420 3
- CHEM 443 3
- Elective 3
- Fine Arts or Literature 3

**Second Semester**
- CHEM 423 3
- CHEM 434 3
- Elective 3

**Notes:**

1. Substitution with permission only.
2. Linear Algebra/Differential Equations (MATH 228) is a recommended science elective.
3. Undergraduate research, CHEM 498R, is a recommended science elective in all programs beginning in the sophomore year with typically one or two credits per semester.
BACHELOR OF SCIENCE WITH A MAJOR IN BIOCHEMISTRY

The biochemistry curriculum emphasizes the chemical basis of biological processes. All biochemistry majors are required to take the following courses:

- General Chemistry (CHEM 125–126 recommended; or optionally CHEM 113–114 or 117–118)
- Organic Chemistry (CHEM 247, 247L, 248, 248L, 236L may be substituted for 248L)
- Physical Chemistry (CHEM 321-322)
- Analytical Chemistry (CHEM 333, 333L)

Chemistry Seminars (CHEM 201, 202), three semesters

Biochemistry Seminar (CHEM 212)
Biochemistry (CHEM 341, 341L, 342)
Calculus (MATH 125, 126, 225)
Physics (PHYS 221-222)
General Biology (BIOS 161–162 or 201, 201L, 202, 202L)
Genetics (BIOS 303, 303L)
Cell Biology (BIOS 341, 341L)
Molecular Biology (BIOS/CHM 531)

Sample Curriculum (Biochemistry Program):

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Sophomore Year

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Notes (a continuation from above):

8. For alternative physics, take PHYS 131, 132.
9. BIOS 201, 201L, 202, and 202L are alternative choices for the sophomore year.

Chemistry and Biochemistry Course Descriptions.

The following course descriptions give the number and title of each course. Lecture hours per week, laboratory and/or tutorial hours per week and credits each semester are in parentheses.

Chemistry Survey Courses (101–104)

These courses each satisfy one semester of the University science requirement and are designed for students planning programs in areas other than science and engineering. CHEM 101, 103 and 104 assume no previous knowledge of chemistry.

101. Foundations of Chemistry

This course covers forms, properties and separation of matter, atomic structure and periodicity, nuclear chemistry, chemical bonding and structure, reactivity with applications to acid-base and oxidation-reduction reactions, chemistry of carbon and living systems. This course is not open to students who have taken CHEM 103, 113, 115 or 117.

102. Chemistry, Environment, and Energy

Prerequisite: CHEM 101 or permission of the instructor.

Chemistry of the atmosphere, hydrosphere and lithosphere, agricultural chemistry and pesticides, food and drugs, hazardous and solid wastes, recycling. Fossil fuels; nuclear, solar, geothermal and other types of energy. This course is not open to students who have taken CHEM 114, 116 or 118.

103. Chemistry in Society

This course introduces students to the chemical component of various interests and concerns of our society. In the context of this introduction, it acquaints students with some of the basic conceptual tools that chemists use, such as ideas of bonding in chemical compounds, the chemical view of acids and bases, and calculation of the amount of material consumed or produced in a chemical reaction. The ozone layer, global warming, solar energy, plastics and nutrition are among the topics to be covered. This course is not open to science majors and students who have taken CHEM 101, 102, 113, 115, or 117.

104. Light: Principles and Applications

The course is designed to provide the student with an understanding of the nature of light, its interaction with matter and the consequences of this interaction in everyday phenomena as well as in the newer technologies such as lasers, photodynamic therapy, photo-imaging and photolithography, holography, and solar energy storage. Discussions of everyday phenomena would include photosynthesis, color and dyes, polarized light, photochemical smog and the ozone layer, optical activity and structure, vision, and photochromism. Necessary concepts of chemistry, physics and biology will be provided. This course is not open to science and engineering majors.
113–114. General Chemistry I-T and II-T Lecture, Tutorial, and Laboratory
(3-4-4) (3-4-4)
Prerequisites: High school chemistry and physics, three-and-one-half units of high school mathematics.
Introduction to the principles and concepts of chemistry and its application in the world. Topics include periodic properties of the elements, reaction stoichiometry, atomic theory, molecular structure and bonding, acids and bases, reduction-oxidation reactions, gas-laws, thermochemistry, equilibrium, and chemical kinetics. Lectures, demonstrations, laboratory experiments and tutorial sections are integrated to promote a deeper understanding of chemistry fundamentals and to develop the analytical skills necessary for solving problems. In the weekly tutorials, students work in small groups at solving problems collaboratively. The general topics, textbook and laboratory are the same as those for CHEM 117–118. CHEM 114 will serve as a prerequisite course to all upper-level courses which list CHEM 118 or CHEM 126 as a prerequisite.

115–116. General Chemistry I and II Lecture
(3-0-3) (3-0-3)
Prerequisites: High school chemistry and physics, three-and-one-half units of mathematics.
Designed for first-year students intending to major in science and engineering. This lecture course covers classical/modern chemistry, with applications, in the approximate order: stoichiometry and classical atomic theory of chemistry; periodic properties; gas laws; chemical equilibrium; solution chemistry (acids and bases, solubility, physical properties of solution); thermochemistry; chemical kinetics; modern quantum theory of atomic and molecular structure and periodic properties.

Descriptive chemistry is included throughout in all developments. Frequent live demonstrations and classroom computer use emphasize the unifying experimental and theoretical aspects of the subject.

117–118. General Chemistry I and II Lecture and Laboratory
(3-3-4) (3-3-4)
Identical to CHEM 115–116 except for including a laboratory. The lab introduces experimental chemistry with examples from all areas of chemistry. The experiments range from traditional wet chemistry to modern instrumental analysis. The lab consists of prelab lecture and individual laboratory work. In both semesters, computers are integrated into the experiments. The computer programs are intended to promote certain problem-solving skills and provide experimental simulation not possible within the time constraints of the normal laboratory period.

119L–120L. General Chemistry Laboratory
(0-3-1) (0-3-1)
A laboratory identical to that presented in conjunction with CHEM 117–118. Designed for students needing laboratory but having previously taken CHEM 115–116.

121–122. General Chemistry: Fundamental Principles and Biological Processes
(3-3-4) (3-0-3)
Prerequisites: High school chemistry and physics, three-and-one-half units of mathematics.
Designed for first-year students intending to major in engineering. In the first semester, the fundamental principles of chemistry are presented including atomic and molecular structure, molecular properties, periodic trends in reactivity, solution chemistry, thermodynamics and kinetics. Quantitative aspects are stressed. A laboratory is offered with this part of the course. In the second semester, these topics are woven into key themes of modern biology, including protein structure and function, gene structure and manipulation, and basics of biotechnology. Emphasis is placed on common themes rather than biological details, and examples are drawn from biological systems of interest to engineers. This course will serve as a prerequisite course to all upper-level courses which list CHEM 118 or CHEM 126 as a prerequisite.
212. Biochemistry Seminar (1-0-0)
A zero-credit seminar course offered in the fall term for sophomore biochemistry majors only. The seminar seeks to acquaint the biochemistry majors with (1) the biochemistry faculty members, (2) the types of research programs in biochemistry that are being carried out in the department and (3) some general biochemistry concepts. Each meeting will be conducted by a different member of the biochemistry faculty.

223–224. Elementary Organic Chemistry I and II (3-0-3) (3-0-3)
Prerequisite: CHEM 114, 116, 118, 122, or 126.
Elements and principles of organic chemistry, with emphasis on structure-reactivity relationships.

223L–224L. Elementary Organic Chemistry Laboratory I and II (0-3-1) (0-3-1)
Prerequisite: CHEM 223-224.
Organic reactions and procedures.

235–236. Organic Chemistry M I and II (3-0-3) (3-0-3)
Prerequisite: CHEM 114, 116, 118, or 126.
A thorough treatment of the basic principles of organic chemistry, including modern structural concepts, the effect of structure on physical and chemical properties, reactions, and their mechanisms and applications in synthesis. Intended primarily for chemistry majors.

235L. Organic Chemistry M Laboratory I (1-3-1)
Corequisite: CHEM 235.
A course designed to introduce students to the laboratory techniques of organic chemistry.

236L. Organic Chemistry M Laboratory II (1-6-2)
Prerequisite: CHEM 235L.
Corequisite: CHEM 236.
Fundamental organic reactions and the preparation of organic compounds.

243. Inorganic Chemistry (3-0-3)
Prerequisite: CHEM 114, 116, 118 or 126.
Descriptive chemistry of both main group and transition metal elements, emphasizing periodic trends in structure and reactivity and using the concepts of atomic theory, elementary bonding theory and ligand field theory. Introduction to inorganic thermodynamics and solution chemistry.

247–248. Organic Chemistry I and II (4-0-4) (4-0-4)
Prerequisites: CHEM 114, 116, 118 or 126.
Prerequisite or Corequisite: BIOS 162 or 201. (For sophomore biology and biochemistry majors only.)
Basic principles of organic chemistry, including structure, stereochemistry, reaction mechanisms, synthesis, and reactions of important classes of organic compounds and their relationships to biochemical and biological systems. For students having an interest in chemistry as it relates to the life sciences.

321–322. Physical Chemistry I and II (3-0-3) (3-0-3)
Prerequisites: CHEM 114, 116, 118 or 126; MATH 126 or 166; and PHYS 132 or 222.
A rigorous course in the fundamentals of physical chemistry, including chemical thermodynamics, kinetics and the elements of atomic and molecular structure.

321–322L. Physical Chemistry Laboratory I and II (0-4-2) (0-4-2)
Prerequisites: To be taken concurrently with CHEM 321-322.
A course in the experimental aspects of physical chemistry, using modern techniques of measurement. The first semester emphasizes thermodynamic and kinetic measurements. The second semester emphasizes spectroscopic measurements, including electronic, infrared, Raman and nuclear magnetic resonance spectroscopies, and measurements in reaction dynamics.

324. Physical Chemistry for Engineers (3-0-3)
Prerequisites: CHEM 114, 116, 118, or 126; PHYS 132; MATH 225.
A course in the fundamentals of physical chemistry, emphasizing theoretical and experimental aspects of reaction kinetics, an introduction to quantum theory and a critical appreciation of the nature of the chemical bond. The course also explores how spectroscopic techniques allow us to gain insight into the structure and properties of molecules. Spring.

331. Chemistry in Service of the Community (1-0-1)
Corequisite: CHEM 333 and 333L.
Addressing the problem of lead contamination in the community, students will visit area homes and collect paint, dust, and soil samples. After analyzing these samples in CHEM 333L, students will help homeowners reduce the health risks associated with exposing young children to lead.
Environmental Sciences

Director, Associate Professor of Biological Sciences:
Paul R. Grimstad

Program in Environmental Sciences. The form and function of planet Earth have been changed as a result of the activities of humans. Current concerns, such as environmental pollution and global warming, are the results of complex processes. It is now important for people in all walks of life to be aware of how we interact with the Earth and how environmental changes will affect us in the future.

The environmental sciences major is an interdisciplinary program designed to build sensitivity and breadth in environmental areas. The curriculum is designed to expose students to a scientific view of our environment from biological, chemical and geological perspectives. Particular emphasis is placed on understanding how humans interact chemically and biologically with the environment. Material and energy resource limitations, chemical and thermal pollution, and effects of environmental pollution on public health are major considerations within the environmental sciences curriculum. Emphasis is also placed on understanding interactions between human societies and the environment from social, ethical, economic, anthropological, and governmental points of view. Students are also encouraged to strengthen their mathematical and computational skills and to participate voluntarily in environmentally oriented research projects or summer internships.

The First Major. College of Science students who major in Environmental Sciences will earn the degree of bachelor of science. Students following the Environmental Sciences first major program complete a total of 69 credits of science. A second major in Environmental Science is also offered to students in the College of Arts and Letters or in the Mendoza College of Business.

The Second Major for Arts and Letters and Business: Most students in the College of Arts and Letters or in the Mendoza College of Business may participate in the Environmental Sciences Program as a second major. Second majors are required to complete a minimum of 37 credits of science. Students considering this program should investigate options brought to a first major by adding course work in environmental sciences. For example, students majoring in government and in environmental sciences could consider postgraduate study or careers in public policy. Students majoring in economics and in environmental sciences would have a good background for the developing field of environmental economics. A second major in Environmental Sciences also complements majors in the other sociological fields of anthropology, psychology, or sociology. Similarly, business students will likely find environmental sciences to be useful background when working with local or federal governments on issues of environmental compliance or when considering the impact of business decisions on the environment.
(environmental assessment). All students are urged to discuss their long-range career plans with advisors in both majors.

**Relationship with Other Programs:** The Environmental Sciences Major Program has a special collaborative relationship with the Science, Technology, and Values (STV) Concentration program housed in the Reilly Center in O’Shaughnessy Hall. Many of the courses required of environmental sciences first majors are also crosslisted as STV courses. Thus, students in the STV program from across the university are expected to benefit in the curricular endeavors of the Environmental Sciences Program. Environmental sciences first majors often enroll in the STV program. (Environmental science students with flexibility in their program may have room to complete a STV concentration by taking STV courses beyond those required by the first major or university requirements.) However, arts and letters students with second majors in environmental science will be encouraged to participate in further interdisciplinary course work through the STV concentration. Second majors are especially encouraged to take the capstone course, SC 491, Current Topics in Environmental Science, as part of the STV concentration.

**Related Options:** A similar bachelor’s degree program, Environmental Geosciences (ENVG), is offered by the College of Engineering.

- Also available through the College of Engineering is the Environmental Geosciences minor. Note: for students in ES (or SCBU, SCCO, and SCED); the College of Science will allow the course SC/ENVG 231 to count toward both the science major and this major. Any courses taken for completion of this minor may not also be counted as science electives or science requirements for a science major.

**BACHELOR OF SCIENCE WITH A MAJOR IN ENVIRONMENTAL SCIENCES**

All environmental sciences first majors take the following courses in science:

- General Biology (BIOS 201–202 and 201L–202L)
- General Chemistry (CHEM 117–118)
- Calculus (MATH 119–120 or 125–126)
- Geology (ENVG 231)
- Physics (PHYS 131–132 or 221–222)
- Biostatistics (BIOS 411)
- Ecology (BIOS 312)
- Chemistry elective
- Current Topics in Environmental Science (SC 491)

Students also will choose science electives chosen from an approved list, completing a required minimum total of 69 credits in science.

Also required for the major are the following non-science courses:

- Environmental Ethics (PHIL 247) or Science, Technology, and Society (PHIL 256) or approved substitute (PHIL, THEO, other).

**Introduction to Economics** (ECON 101 or 201)\(^3\)

Students are also urged to choose their electives from a recommended list of ISP\(^*\) courses and arts and letters courses.\(^4\)

Requirements for the program are summarized in the table on the next page.

**Notes:**

1. Equivalent or higher-level sequences in science may be substituted, e.g., CHEM 113–114 or CHEM 125–126 for CHEM 117–118 or BIOS 161–162 for BIOS 201–202 or MATH 165–166 for MATH 125–126.
2. Students interested in the area of ecological modeling are strongly urged to take MATH 125–126 for their mathematics requirement. Other mathematics courses should be taken as science electives.
3. Students who have completed only six hours of mathematics in their first year may transfer into the program, but they will be required to complete a mathematics sequence equivalent to MATH 119, 120 or MATH 125, 126. Students having taken MATH 105, 106 (or 108 or 110) may do this by taking MATH 120, while those who have taken only one semester of lower-level calculus should take both MATH 119, 120. (See also the discussion on science degree credit found later in this section of the Bulletin.)
4. The chemistry elective requirement is satisfied by either one first course in organic chemistry (CHEM 223, 223L or CHEM 235, 235L or CHEM 247, 247L) or Inorganic Chemistry (CHEM 243) or by Analytical Chemistry (CHEM 333, 333L).
5. The following are the primary approved science electives for this program:
- Botany (BIOS 304)
- Evolution (BIOS 305)
- The History of Life (BIOS 310)
- Plant Science (BIOS 325)
- Principles of Microbiology (BIOS 401)
- Animal Behavior (BIOS 407)
- Aquatic Ecology (BIOS 420)
- Stream Ecology (BIOS 527)
- Other BIOS courses as designated by the ES director, including 500-level graduate courses are accepted.

<table>
<thead>
<tr>
<th>Courses</th>
<th>Credits</th>
</tr>
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<tbody>
<tr>
<td>Biological Sciences</td>
<td>16</td>
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<tr>
<td>Chemistry</td>
<td>11-13</td>
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<tr>
<td>Geology</td>
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<tr>
<td>Mathematics</td>
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<td>Physics</td>
<td>8</td>
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<tr>
<td>SC 491</td>
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<tr>
<td>Science Electives</td>
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<tr>
<td><strong>Total Science</strong></td>
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<td>FYC 110</td>
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<tr>
<td>Philosophy*</td>
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<tr>
<td>Theology*</td>
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<tr>
<td>History*</td>
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</tr>
<tr>
<td>Social Science</td>
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</tr>
<tr>
<td>Literature/Fine Arts*</td>
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</tr>
<tr>
<td>Free Electives**</td>
<td>22**</td>
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<tr>
<td><strong>124</strong></td>
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</tr>
</tbody>
</table>

\(^*\) One of these courses must be a University Seminar 180.

\(**\) Assumes intermediate-level competency in language was achieved by taking three 3-credit courses.
Sample Curriculum (B.S. Degree Majors):

First Year

<table>
<thead>
<tr>
<th>Semester</th>
<th>Course</th>
<th>Credits</th>
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<tbody>
<tr>
<td>First</td>
<td>CHEM 117. General Chemistry I</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>MATH 119. Calculus A</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>FYC 110</td>
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<tr>
<td></td>
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<td></td>
<td>Physical Education/ROTC</td>
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<tr>
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Second Semester

<table>
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<tr>
<th>Semester</th>
<th>Course</th>
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</tr>
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<tbody>
<tr>
<td>CHEM 118. General Chemistry II</td>
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</tr>
<tr>
<td>MATH 120. Calculus B</td>
<td>4</td>
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</tr>
<tr>
<td>Fine Arts/Literature*</td>
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</tr>
<tr>
<td>Philosophy*</td>
<td>3</td>
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</tr>
<tr>
<td>ECON 115</td>
<td>3</td>
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<tr>
<td>Physical Education/ROTC</td>
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</tr>
<tr>
<td></td>
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Sophomore Year

<table>
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<tr>
<th>Semester</th>
<th>Course</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>First</td>
<td>BIOS 201. General Biology A**</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>BIOS 201L: General Biology A Lab</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>ENVG 231. Physical Geology</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Language</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>PHIL 247 or 256</td>
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Second Semester

<table>
<thead>
<tr>
<th>Semester</th>
<th>Course</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>BIOS 202. General Biology B**</td>
<td>3</td>
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</tr>
<tr>
<td>BIOS 202L: General Biology B Lab</td>
<td>1</td>
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<tr>
<td>CHEM elective or science elective</td>
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<tr>
<td>Language</td>
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<tr>
<td>Elective*</td>
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<td></td>
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Junior Year

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<th>Semester</th>
<th>Course</th>
<th>Credits</th>
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</thead>
<tbody>
<tr>
<td>First</td>
<td>BIOS 312. General Ecology</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>PHYS 221. General Physics I</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Elective (or Language)</td>
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</tr>
<tr>
<td></td>
<td>Theology</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Elective*</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>17</td>
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</table>

Second Semester

<table>
<thead>
<tr>
<th>Semester</th>
<th>Course</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOS 411. Biostatistics</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>PHYS 222. General Physics II</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Science Elective</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Elective*</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>17</td>
<td></td>
</tr>
</tbody>
</table>

Notes (a continuation from above):

10. As is the case for science first majors, six credits of the science course work in this program will also be counted toward the student's university science requirement.
11. This requirement is satisfied by either one first course in physics (PHYS 115 or 131 or 151 or 221) or an approved survey course: Concepts of Energy and the Environment (PHYS 104) or Technological Risk (PHYS 176) or Energy and Society (PHYS 204) and others as designated.

12. Although mathematics course work is not specifically required of this program, several required courses (BIOS 411 or some of the first courses in physics) do have a prerequisite of one year of calculus (MATH 119–120 or equivalent). For all students in the College of Arts and Letters or the Mendoza College of Business, the mathematics sequence MATH 119–120 is acceptable for completion of the university mathematics requirement; thus, this sequence is recommended for students considering Environmental Sciences as a second major. Students lacking this mathematics background may have to take further course work in mathematics in order to meet the prerequisites in mathematics of courses in this program.

13. Chosen from approved biology or geology electives listed in note 6 above.

Sample Curriculum (Second Majors):

Students should remember that all science major programs require course work that builds upon prerequisites and thus require careful planning. A suggested curriculum for second majors is given below. Note: Only the courses for the second major are listed.

**First Year**

**First Semester**

CHEM 117. General Chemistry I 4

**Second Semester**

CHEM 118. General Chemistry II 4

**Sophomore Year**

**First Semester**

BIOS 201. General Biology A 3

BIOS 201L: General Biology A Lab 1

**Second Semester**

BIOS 202. General Biology B 3

BIOS 202L: General Biology B Lab 1

**Junior Year**

**First Semester**

ENVG 231. Physical Geology 4

PHYS 204. Energy and Society 3

**Second Semester**

BIOS 411. Biostatistics 4

CHEM 204. Environmental Chemistry 3

**Senior Year**

**First Semester**

BIOS 312. General Ecology 4

**Second Semester**

BIOS or ENVG Elective 3–4

* MATH 119–120 or equivalent are not included in the minimum total of 37 credits in this sequence; satisfies the University math requirement.

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### SUMMARY OF REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE IN MATHEMATICS

(For other programs see the Department of Mathematics)

<table>
<thead>
<tr>
<th>Mathematics Program</th>
<th>Mathematics Career Program</th>
<th>Mathematics and Computing Program</th>
<th>Mathematics and Life Sciences Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematics</td>
<td>46</td>
<td>42</td>
<td>42</td>
</tr>
<tr>
<td>Chemistry</td>
<td>8</td>
<td>8</td>
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</tr>
<tr>
<td>Physics</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Biological Sciences</td>
<td>—</td>
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</tr>
<tr>
<td>Science Elective</td>
<td>3</td>
<td>3</td>
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</tr>
<tr>
<td>Language</td>
<td>Intermediate Level Competency</td>
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<td>FYC 110</td>
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<tr>
<td>Philosophy*</td>
<td>6</td>
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<tr>
<td>Theology*</td>
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<tr>
<td>Social Sciences*</td>
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<tr>
<td>History*</td>
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<tr>
<td>Literature/Fine Arts*</td>
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</tr>
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<td>Engineering</td>
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<td>15</td>
<td>—</td>
</tr>
<tr>
<td>Free Electives</td>
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<td>30&quot;</td>
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<tr>
<td>Total</td>
<td>124</td>
<td>124</td>
<td>124</td>
</tr>
</tbody>
</table>

* One of these courses must be a University Seminar 180.

** Assumes intermediate level competency in language was achieved by taking three-credit courses.

---

### Mathematics

**Chair:**

William G. Dwyer

**Associate Chair:**

Alex A. Himonas

**Director of Graduate Studies:**

Julia Knight

**Director of Undergraduate Studies:**

Juan Migliore

**William J. Hank Family Professor of Mathematics:**

William G. Dwyer

**Charles L. Huisking Professor of Mathematics:**

Julia F. Knight

Vincent J. Duncan and Annamarie Micus Duncan Professor of Mathematics:

Andrew Sommese

**John A. Zahm, C.S.C., Professor of Mathematics:**

Stephen A. Stolz

**Kenna Associate Professor of Mathematics:**

Xiaobo Liu

**John and Margaret McAndrews Professor of Mathematics:**

Francois Ledrappier

---

**Professors:**

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**Program of Studies.** Mathematics has had a profound effect upon civilization since ancient times, when the legend originally inscribed on the entrance to Plato's academy was “Let no one ignorant of geometry enter here.” It was equally true during the medieval period, when arithmetic and geometry constituted two of the seven subjects considered essential for a liberal education. It has been said that the second most influential book in the span of Western civilization—after the Bible—is Euclid's *Elements*. Although mathematics is usually associated with science and technology in the modern mind, it seems apparent from the writings of the great mathematicians of the 17th and 18th centuries that religious belief played a great role in their pursuit of mathematics. They saw the “system of the world” obeying mathematical laws and as a consequence felt impelled to study mathematics so as to better appreciate the world's Creator.

Mathematics continues to have a profound influence in our century. From the theory of relativity, with its applications to the study of the large-scale structure of the universe, to the development of the modern computer, with its manifold applications in science, technology and business, mathematics has played a fundamental role. It is surely the most universal of all scientific tools, and the student equipped with a strong mathematical background will be in the enviable position of being able to employ his or her expertise in any area in which rigorous thought and precision of results are mandated.

The department is dedicated to the development of undergraduate studies, to the teaching of mathematics to scientists, engineers and teachers, to graduate education and research, and to the discovery of new mathematics. The entire faculty is involved with undergraduate affairs, and students have the opportunity of associating with scholars of international repute. Mathematics at Notre Dame provides students with a discipline of the mind and a stimulation of the imagination par excellence.

Programs in mathematics prepare students for graduate studies or for professional work in fields in which mathematics plays a dominant role. They provide an excellent preparation for law school, medical school, business school and secondary school teaching. Graduates may enter careers in research institutes or industrial or government positions.

In addition to its undergraduate programs, the department offers programs of graduate study leading to the degree of doctor of philosophy, as described in the Graduate School *Bulletin of Information*.

The department recognizes that, besides those students who wish to pursue a career devoted primarily to mathematical research and teaching, many will wish to take positions in business, industry or government where they will be using their mathematical skills in close collaboration with engineers as well as biological, physical and social scientists. These students will find among the listed programs one well suited to their needs. Besides these programs a student may, in consultation with the director of undergraduate studies and the department chair, create a program especially tailored to his or her career goals.

**Bachelor of Science with a Major in Mathematics.** The mathematics curriculum at Notre Dame includes nine course sequences or areas of concentration within the College of Science. These programs are designed to accommodate the academic and professional interests of all mathematics majors. Brief descriptions are given below, and more detailed descriptions of these programs are available on request from the Department of Mathematics.

**College Requirements.** All must take the following College of Science courses: CHEM 117, 118; PHYS 131, 132; and an additional science elective.

A student who takes two semesters of organic chemistry or two semesters of general biology is only required to take PHYS 221-222.

**Mathematics Honors Program**

This program is suited to students who are interested in graduate work in one of the mathematical sciences and to those whose career plans require a strong background in modern mathematics.

**Mathematics Courses for the Other Programs**

All other mathematics programs (except the computing program) require the following mathematics core courses:

- Calculus I (MATH 125)
- Calculus II (MATH 126)
- Calculus III (MATH 225)
- Ordinary Differential Equations (MATH 230)
- Linear Algebra (MATH 221)
- Introduction to Abstract Math (MATH 223)
- Algebra (MATH 337)
- Real Analysis (MATH 338)
- Computer Programming (MATH 211)

In addition to this basic sequence, the following courses are required for each program:

**Mathematics Career Program**

This program is designed to give students a general background in mathematics. In addition to the basic sequence of courses listed above, 12 hours of mathematics electives are required, at least three of which are at the 400 level.
Applied Mathematics Program
This program is designed for students interested in the broader area of applied mathematics. In addition to taking the core mathematics courses, the student is required to take 15 credits from the following list of courses, six credits of which must be at the 400 level: MATH 311, MATH 318, MATH 323, MATH 324; MATH 405, MATH 423, MATH 424, MATH 425, MATH 433, MATH 434, MATH 436, and MATH 441.

Mathematics and Life Sciences Program
This program is designed for mathematics majors who are interested in life-science-oriented careers. The following mathematics courses are required in addition to the basic sequence of courses listed above:

- Introduction to Probability (MATH 323)
- Mathematical Statistics (MATH 324)
- Elective in Mathematics (three credit hours at the 400 level)

The following College of Science courses are required:

- Organic Chemistry (CHEM 223, 223L; 224, 224L)
- General Biology (BIOS 201, 201L; 202, 202L)
- Genetics (BIOS 303, 303L)

Mathematics and Computing Program
This program is designed for students who plan to pursue graduate study or industrial careers in computing science. All of the mathematics core courses listed above except MATH 211 are required, as well as 15 hours of mathematics electives, at least three hours of which are at the 400 level.

In addition, the student must complete one of the following sequences of computing courses:

- Software design option: CSE 211, CSE 212, CSE 210, CSE 331, CSE 346, fourth elective
- Theory option: CSE 211, CSE 212, CSE 210, CSE 331, CSE 411, CSE 413
- Theory and compilers option: CSE 211, CSE 212, CSE 210, CSE 331, CSE 411, CSE 443
- Computer architecture option: CSE 211, CSE 212, CSE 221, CSE 321, CSE 322, fourth elective

Mathematics Education Program
This program is designed for students who plan a career in secondary education. The following mathematics courses are required in addition to the basic sequence listed above:

- Introduction to Probability (MATH 323)
- Mathematical Statistics (MATH 324)
- Elective in Geometry (three credit hours)
- Elective in Mathematics (three credit hours)

(One of these classes must be at the 400 level)

The following education courses are to be taken at Saint Mary’s College: EDUC 201, 220, 340, 350, 356, 404, 451, and 475.

Mathematics and Business Administration Program
This program is designed to prepare students for a career in business or in the actuarial profession. The following mathematics courses are required in addition to the basic sequence:

- Introduction to Probability (MATH 323)
- Mathematical Statistics (MATH 324)
- Introduction to Operations Research (MATH 311)
- Elective in Mathematics (three credits at the 400 level)

Also required are ECON 201 or its equivalent and the following courses from the College of Business: ACCT 231, FIN 231, MARK 231, MGT 231 and one course from the following list: ACCT 232, FIN 360, FIN 361, FIN 370, MGT 350, MGT 473, MARK 370.

Mathematics and Engineering Science Program
This program is designed for students interested in applied or industrial mathematics. In addition to the mathematics core courses, the student is required to take one of MATH 425, MATH 423 or MATH 436, and nine more credits of mathematics electives. The student must also complete one of the following two sequences of engineering classes:

- Thermal option: AME 225, AME 226, AME 334, AME 327, AME 439
- Structures and design option: AME 225, CE 236, AME 327, CE 336, CE 356

Mathematics and Social Science Program
This program is designed for students planning graduate school or a career in one of the social sciences with a strong mathematics and statistics background. In addition to the basic sequence, the following mathematics courses are required:

- Introduction to Probability (MATH 323)
- Mathematical Statistics (MATH 324)
- Introduction to Operations Research (MATH 311)
- Elective in Mathematics (three credits at the 400 level)

Moreover, the student must elect introductory courses in three of the social sciences, SOC 302 and two courses at the 300 or 400 level in one of the social sciences.

Mathematics as a Second Major
Students in the Mendoza College of Business or the College of Arts and Letters may pursue a second major in mathematics by completing all mathematics courses required for the career mathematics concentration. See the list below. To list mathematics as a second major on the transcript, the student must satisfy all of the requirements for a major in some department of the Mendoza College of Business or the College of Arts and Letters.

- MATH 125–126-225. Calculus I-III 11.5
- MATH 230. Ordinary Differential Equations 3.5
- MATH 211. Computer Programming and Problem Solving 3
- MATH 221. Linear Algebra 3
- MATH 223. Introduction to Abstract Math 3
- MATH 337. Algebra 3
- MATH 338. Real Analysis 3
- Mathematics electives 9*
- Mathematics elective at the 400 level 3*

42 credits

* Students majoring in finance and business economics may reduce the number of mathematics electives to nine credits total by taking the following courses: MATH 323, MATH 324, and MATH 517.

Sample Curriculum
(Mathematics Career Program):

First Year
First Semester
MATH 125, Calculus I 4
CHEM 117, General Chemistry I 4
PHYS 131, General Physics I 4
History or Social Science 1 3
FYC 110 3
Physical Education or ROTC —

18

Second Semester
MATH 126, Calculus II 4
CHEM 118, General Chemistry II 4
PHYS 132, General Physics II 4
History or Social Science 1 3
Philosophy or Theology 3
Physical Education or ROTC —

18

Sophomore Year
First Semester
MATH 221, Linear Algebra 3
MATH 225, Calculus III 3.5
Language 3
Philosophy or Theology 3
Science Elective 3

15.5

Second Semester
MATH 211. Computer Programming and Problem Solving 3
MATH 223, Introduction to Abstract Math 3
MATH 230. Ordinary Differential Equations 3.5
Language 3
Philosophy or Theology 3

15.5

Elective in Mathematics (three credit hours at the 400 level) 3

24 credits
### Mathematics

#### Junior Year

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<td>Elective</td>
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<td>15</td>
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<tr>
<td>Second Semester</td>
<td>MATH 338. Real Analysis</td>
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<td></td>
<td>Literature or Fine Arts</td>
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#### Senior Year

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<td>Second Semester</td>
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<td>Electives</td>
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1. The student should take three general requirement courses during the first year, including one course that is designated a University Seminar 180. It is recommended that one course in history or social science be taken in the first year and one philosophy and one theology course be taken by the end of the sophomore year.

### Mathematics Course Descriptions

#### 103. Processes of Mathematical Thought

**(3-0-3)**

For students in arts and letters or business administration.

A study of mathematical thought as an analytical tool to solve real-life problems. The class is divided into teams, each analyzing a topic from such areas as commercial games, consensus within diversity, human and bacterial populations, the dynamics of money, and basic economics.

#### 104. Finite Mathematics

**(3-0-3)**

For students in arts and letters or as an elective for students in business administration.

Elements of probability, statistics, and matrix theory, with applications including Markov chains, game theory and mathematics of finance.

#### 105. Elements of Calculus I

**(3-0-3)**

For students in arts and letters, architecture, or business.

A study of differential calculus as part of a liberal education. Topics include functions and their graphs, derivatives, and applications.

#### 106. Elements of Calculus II for Business

**(3-0-3)**

Prerequisite: MATH 105 or equivalent, but no prior MATH 110. Credit is not given for both MATH 108 and either of the following courses: MATH 110 and MATH 120. For students in business.

An introduction to the basic concepts of integral calculus, with emphasis on problems arising in business and economics.

#### 107. Principles of Finite Mathematics

**(3-0-3)**

For students in arts and letters.

For first-year students who lack the necessary background for MATH 104. (Students who take this course can not take MATH 104.) Topics include elementary probability, data analysis, statistical inference, and information codes.

#### 108. Elements of Calculus II for Business

**(3-0-3)**

Prerequisite: MATH 105 or equivalent, but no prior MATH 110. Credit is not given for both MATH 108 and either of the following courses: MATH 110 and MATH 120. For students in business.

An introduction to the basic concepts of integral calculus, with emphasis on problems arising in business and economics.

#### 109. Honors Calculus I and II

**(3-0-3)**

Required of honors mathematics majors.

A rigorous course in differential and integral calculus of one variable. Topics include an axiomatic formulation of the real numbers, mathematical induction, infima and suprema, functions, continuity, derivatives, integrals, infinite sequences and series, transcendental functions and their inverses, and Baye’s rule. The methodology will focus on a ‘hands-on’ approach, with use of computer simulation and representation. Concepts and terminology will be introduced only after thorough exposure to situations that necessitate the concepts and terms.

Care will be exercised to select a variety of situations from the many fields where statistics is used in modern society. Examples will be taken from biology and medicine (e.g., drug testing, wild animal counts), the social sciences, psychology, and economics.

#### 110. Elementary Calculus in Action

**(3-0-3)**

Prerequisite: MATH 105 or equivalent. Credit is not given for both MATH 110 and either of the following courses: MATH 108 and MATH 120.

A second calculus course for arts and letters and architecture students. This course uses typical mathematical strategies of elementary calculus and shows these “in action” with studies of the suspension bridge, various nuclear clocks, growth patterns of human and bacterial populations, the dynamics of money, and basic economics.

#### 111. Principles of Calculus

**(3-0-4)**

For students in arts and letters.

Note: Credit is not given for both this course and any other calculus course.

A terminal course introducing the principles of calculus. Topics include basic properties of functions, derivatives, and integrals. This course is not intended to prepare students for more advanced work in calculus.

#### 112. Beginning Logic

**(3-0-3)**

For students in arts and letters.

An introduction to formal languages, systems of proof, and symbolic logic.

#### 113. Beginning Logic

**(3-0-3)**

For students in arts and letters or as an elective for students in business administration.

A second calculus course for arts and letters and architecture students. This course uses typical mathematical strategies of elementary calculus and shows these “in action” with studies of the suspension bridge, various nuclear clocks, growth patterns of human and bacterial populations, the dynamics of money, and basic economics.

#### 114. Elements of Statistics

**(3-0-3)**

This course is aimed to those students who may or may not plan to use statistics in their chosen careers, but wish nevertheless to become informed and astute consumers. Topics include: statistical decision making, sampling, data representation, random variables, least square regression lines, elementary probability theory, conditional probabilities, independence, and Baye’s rule. The methodology will focus on a ‘hands-on’ approach, with use of computer simulation and representation. Concepts and terminology will be introduced only after thorough exposure to situations that necessitate the concepts and terms.

Care will be exercised to select a variety of situations from the many fields where statistics is used in modern society. Examples will be taken from biology and medicine (e.g., drug testing, wild animal counts), the social sciences, psychology, and economics.

#### 115. First-Year Mathematics Seminar

**(3-0-3)**

For students in arts and letters, or as an elective for students in architecture or business administration.

Students in the College of Science may not receive science credit for MATH 115.

A non-calculus course designed to give the students a view of the beauty, importance, and ubiquity of mathematics in our lives and our society. The topic and instructor will vary from semester to semester.

#### 119–120. Calculus A and B

**(3-1-4)** *(3-1-4)*

Primarily for students in science whose programs require a one-year terminal course in calculus of one variable but also open to students in arts and letters.

Topics include sets, functions, limits, continuity, derivatives, integrals, and applications.

#### 125–126. Calculus I and II

**(3-1-4)** *(3-1-4)*

For students in science and engineering.

Topics include sets, functions, limits, continuity, derivatives, integrals, and applications. Also covered are transcendental functions and their inverses, infinite sequences and series, parameterized curves in the plane, and polar coordinates.

#### 165–166. Honors Calculus I and II

**(4-0-4)** *(4-0-4)*

Required of honors mathematics majors.

A rigorous course in differential and integral calculus of one variable. Topics include an axiomatic formulation of the real numbers, mathematical induction, infima and suprema, functions, continuity, derivatives, integrals, infinite sequences and series, transcendental functions and their inverses, and applications. The course stresses careful mathematical definitions and emphasizes the proofs of the standard theorems of the subject.
195–196. Honors Mathematics I and II
(4-0-4) (4-0-4)
Open only to students in the Arts and Letters/Science Honors Program.
A survey of several mathematical topics, emphasizing the relevance of mathematics to many diverse areas of study. Calculus is also studied at the level of MATH 119–120.

211. Computer Programming and Problem Solving
(3-0-3)
Prerequisite: MATH 221 or MATH 261 or equivalent.
An introduction to solving mathematical problems using computer programming in high-level languages such as C. For mathematics majors, credit is not given for both MATH 211 and CSE 232.

214. Introduction to Statistics
(3-0-3)
Prerequisite: MATH 120 or equivalent.
An introduction to the principles of statistical inference following a brief introduction to probability theory. This course does not count as a science or mathematics elective for mathematics majors. NOTE: Students may not take both BIOS 411 and MATH 214. Not open to students who have taken MATH 324.

221. Linear Algebra
(3-0-3)
Open to all students.
An introduction to vector spaces, matrices, linear transformations, inner products, determinants, and eigenvalues. Emphasis is given to careful mathematical definitions and understanding the basic theorems of the subject.
Credit is not given for both MATH 221 and MATH 228.

223. Introduction to Abstract Mathematics
(3-0-3)
Open to all students.
The goal of this course is to introduce students to the level of rigor and the techniques of writing proofs that will be assumed in their upper level courses. The vehicle for this is a careful study of numbers. Topics will include sets, relations, functions, the integers and integers modulo n, the rational numbers, the real numbers, cardinality and countability, sequences, convergence, completeness, Cantor’s diagonalization argument, the topology of the real numbers, and compactness.

225. Calculus III
(3-1-3.5)
Prerequisite: MATH 126 or equivalent.
A comprehensive treatment of differential and integral calculus of several variables. Topics include space curves, surfaces, functions of several variables, partial derivatives, multiple integrals, line integrals, surface integrals, Stokes’ theorem, and applications.

228. Introduction to Linear Algebra and Differential Equations
(3-1-3.5)
Prerequisite: MATH 225.
An introduction to linear algebra and to first- and second-order differential equations. Topics include elementary matrices, LU factorization, QR factorization, the matrix of a linear transformation, change of basis, eigenvalues and eigenvectors, solving first-order differential equations and second-order linear differential equations, and initial value problems.
This course is part of a two-course sequence that continues with MATH 325. Credit is not given for both MATH 228 and MATH 221.

230. Ordinary Differential Equations
(3-1-3.5)
Prerequisites: MATH 225 and MATH 221.
An introduction to differential equations. Topics include first-order equations, n-th order linear equations, power series methods, systems of first order linear equations, non-linear systems, and stability.
Credit is not given for both MATH 230 and MATH 325.

261–262. Honors Algebra I and II
(3-0-3) (3-0-3)
Prerequisite: MATH 166.
A comprehensive treatment of vector spaces, linear transformations, inner products, determinants, eigenvalues, tensor and exterior algebras, spectral decompositions of finite-dimensional symmetric operators, and canonical forms of matrices. The course stresses careful mathematical definitions and emphasizes the proofs of the standard theorems of the subject.

265–266. Honors Calculus III and IV
(4-0-4) (4-0-4)
Prerequisite: MATH 166.
Required of honors mathematics majors.
A rigorous course in differential and integral calculus of several variables. Topics include functions of several variables, the inverse function theorem, partial derivatives, multiple integrals, line integrals, surface integrals, Stokes’ theorem, an introduction to ordinary differential equations, and applications.
The course stresses careful mathematical definitions and emphasizes the proofs of the standard theorems of the subject.

(3-1-3.5)
Prerequisite for MATH 271: MATH 126 or equivalent.
Corequisite for MATH 271: MATH 225 or equivalent.
Prerequisite for MATH 272: MATH 271.
A study of methods of mathematical physics. Topics include matrices, linear algebra (including matrices and determinants), vector and tensor analysis, vector calculus, curvilinear coordinates, series, ordinary differential equations, partial differential equations, orthogonal functions and vector spaces, special functions (including Bessel, Legendre, and Hermite), calculus of variations, Fourier series, and group theory.
Weekly tutorial sessions: Students taking the MATH 271–272 sequence cannot get credit for MATH 228, 230, or 325.

311. Introduction to Operations Research
(3-0-3)
Prerequisite: MATH 221 or equivalent.
An introduction to linear programming, duality theory, simplex algorithm, the transportation problem, network analysis, dynamic programming, and game theory.

312. Probabilistic Models in Operations Research
(3-0-3)
Prerequisite: MATH 323 or equivalent.
An introductory survey of probability theory, queuing theory, inventory theory, Markovian decision theory, and applications.

318. Introduction to Numerical Methods
(3-0-3)
Prerequisites: MATH 228 or MATH 230 and MATH 211 or CSE 232.
An introduction to numerical methods for solving algebraic and differential equations. Topics include numerical solution of systems of linear equations, approximating functions with polynomials and splines, solutions of nonlinear equations, numerical integration, numerical solution of ordinary differential equations, and eigenvalue problems. Some computer programming is required. Credit is not given for both MATH 318 and MATH 423 or PHYS 333.

323. Introduction to Probability
(3-0-3)
Prerequisite: MATH 225 or equivalent.
An introduction to the theory of probability, with applications to the physical sciences and engineering. Topics include discrete and continuous random variables, conditional probability and independent events, generating functions, special discrete and continuous random variables, laws of large numbers, and the central limit theorem. The course emphasizes computations with the standard distributions of probability theory and classical applications of them.
324. Mathematical Statistics
(3-0-3)
Prerequisite: MATH 323 or equivalent.
An introduction to mathematical statistics. Topics include distributions involved in random sampling, estimators and their properties, confidence intervals, hypothesis testing including the goodness-of-fit test and contingency tables, the general linear model, and analysis of variance.

325. Differential Equations
(3-0-3)
Prerequisite: MATH 228.
A second course in differential equations. Topics include higher order linear equations, numerical methods, Laplace transforms, linear systems, non-linear systems and stability, and an introduction to partial differential equations and Fourier series.
Credit is not given for both MATH 230 and MATH 325.

328. Probability and Statistics
(3-0-3)
Prerequisite: Math 225 or equivalent. (Degree credit is not given for MATH 328 and any of the following courses: MATH 214, MATH 323, MATH 324).
An introduction to the theory of probability and statistics, with applications to the computer sciences and engineering. Topics include discrete and continuous random variables, joint probability distributions, the central limit theorem, point and interval estimation, and hypothesis testing.

335–336. Real Analysis I and II
(3-0-3) (3-0-3)
Prerequisite: MATH 225 or equivalent.
A rigorous treatment of fundamentals of differential and integral calculus. Topics include sequences, limits, continuity, differentiability, convergence of sequences of functions, infinite series, and the Riemann-Stieltjes integral. Emphasis is given to careful mathematical definitions and understanding of the basic theorems of the subject.

337. Algebra
(3-0-3)
Prerequisites: MATH 223, 221.
An introduction to groups, rings, and fields. Topics include permutations, divisibility, modular arithmetic, cryptography, cyclic and dihedral groups, Lagrange's theorems, homomorphisms, ideals, integral and Euclidean domains, and extension fields.

338. Real Analysis
(3-0-3)
Prerequisites: MATH 223, 221, 126.
A rigorous treatment of differential and integral calculus. Topics include review of sequences and continuity, differentiability, Taylor's theorem, integration, the fundamental theorem of Calculus, pointwise and uniform convergence, and power series. Additional topics are likely and will depend on the instructor. Emphasis throughout will be on careful mathematical definitions and thorough understanding of basic results.

361–362. Honors Algebra III and IV
(3-0-3) (3-0-3)
Required of honors mathematics majors.
Prerequisite: MATH 262 or equivalent.
A comprehensive treatment of groups, polynomials, rings, homomorphisms, isomorphism theorems, field theory, and Galois theory. The course stresses careful mathematical definitions and emphasizes the proofs of the standard theorems of the subject.

365–366. Honors Analysis I and II
(3-0-3) (3-0-3)
Prerequisite: MATH 266 or equivalent.
Required of honors mathematics majors. An advanced course in mathematical analysis in one and several variables. Topics include an axiomatic formulation of the real and complex number systems, compactness, connectedness, metric spaces, limits, continuity, infinite sequences and series, differentiation, the Riemann-Stieltjes integral, the Stone-Weierstrass theorem, the implicit function theorem, differential forms, partitions of unity, simplexes and chains, and Stokes' theorem.

405. Basic Combinatorics
(3-0-3)
Prerequisite: MATH 225.
An introduction to the theory of combinatorics. Topics include permutations, multinomial coefficients, the theory of enumerative combinatorics, pairing problems, recurrence relations, the inclusion-exclusion principle, graph theory, algebraic coding theory, and symbolic dynamics.

411–412. Topics in Computing
(3-0-3) (3-0-3)
Prerequisites: Programming knowledge and MATH 225.
Topics in computing, artificial intelligence, computer graphics, and file processing.

421. Introduction to Algebraic Geometry
(3-0-3)
Prerequisites: MATH 225, MATH 221, MATH 222.
An introduction to algebraic geometry. Topics include the projective line and plane over the real and complex numbers, algebraic plane curves, tangent lines and singular points, fractional linear transformations, basic elimination theory, affine varieties and their rings of functions, the Nullstellensatz, Grobner bases, and the theory of symmetric functions.

423–424. Numerical Analysis
(3-0-3) (3-0-3)
Prerequisites: Programming knowledge and MATH 230 or MATH 325 or MATH 266 or consent of instructor.
An introduction to the numerical solution of ordinary and partial differential equations. Topics include the finite difference method, projection methods, cubic splines, interpolation, numerical integration methods, analysis of numerical errors, numerical linear algebra and eigenvalue problems, and continuation methods.

425. Complex Variables
(3-0-3)
Prerequisites: MATH 225 or equivalent.
An introduction to the theory of functions of one complex variable. Topics include analytic functions, Cauchy integral theorems, power series, Laurent series, poles and residues, applications of conformal mapping, and Schwarz-Christoffel transformations.

431. Theory of Numbers
(3-0-3)
Prerequisite: MATH 222 or MATH 262, or equivalent.
An introduction to elementary number theory. Topics include the Euclidean algorithm, congruencies, primitive roots and indices, quadratic residues, quadratic reciprocity, distribution of primes, and Waring's problem.

432. Topics in Algebra
(3-0-5)
Topics in algebra, number theory, and algebraic geometry.

433. Modeling and Industrial Mathematics
(3-0-3)
Prerequisites: Programming knowledge and MATH 230 or MATH 325 or consent of instructor.
An introduction to mathematical analysis and numerical computation used in industry today. Topics are chosen from such subjects as crystal precipitation, air quality modeling, color film development, and photocopy machines.

434. Topics in Applied Mathematics
(3-0-3)
Topics in analytic and numerical methods applied to problems in mechanics, electrostatics, and heat flow.

435. Topics in Analysis
(3-0-3)
Topics in analysis, differential equations, and measure theory.

436. Partial Differential Equations
(3-0-3)
Prerequisite: MATH 230 or MATH 325 or equivalent.
An introduction to partial differential equations. Topics include Fourier series, solutions of boundary value problems for the heat equation, wave equation and Laplace's equation, Fourier transforms, and applications to solving heat, wave, and Laplace's equations in unbounded domains.

437. Topics in Geometry
(3-0-3)
Prerequisite: MATH 225 or equivalent.
An introduction to geometry. Topics include non-Euclidean geometry, projective geometry, algebraic geometry of curves, finite geometries, transformation groups in low dimensions, and the crystallographic groups.
438. Differential Geometry
(3-0-3)
Prerequisite: MATH 230 or MATH 325 or equivalent.
An introduction to differential geometry. Topics include analysis of curves and surfaces in space, the first and second fundamental forms of surfaces, torsion, curvature, and the Gauss-Bonnet theorem.

441. Computability and Logic
(3-0-3)
Prerequisite: MATH 126 or equivalent.
An introduction to formal notions of computability. Topics include finite automata, regular languages and expressions, pushdown automata, context-free grammars and languages, Turing machines, primitive recursive and \( \mu \)-recursive functions, Church’s Thesis, and absolutely unsolvable problems. For mathematics majors, credit is not given for both MATH 441 and CSE 411.

461–462. Algebraic and Analytic Number Theory
(3-0-3) (3-0-3)
Prerequisites: MATH 362 and 366 or equivalent.
An introduction to algebraic and analytic number theory. Topics include quadratic reciprocity, diophantine equations, continued fractions, algebraic numbers, the Dirichlet unit theorem, quadratic, cyclotomic extensions, primes in progressions, and the prime number theorem.

463–464. Probability
(3-0-3) (3-0-3)
Prerequisite: MATH 366 or consent of instructor.
A high-level introduction to the theory of probability. Topics include measure theory, probability space, independence, random variables, combinatorial probability, limit laws, and Markov chains.

465–466. Complex Analysis
(3-0-3) (3-0-3)
Prerequisite: MATH 366 or equivalent.
A high-level introduction to the theory of functions of one complex variable. Topics include analytic functions, Cauchy’s theorem, Taylor series, Laurent series, singularities, residue theory, conformal mapping, analytic continuation, Riemann surfaces, entire functions, and meromorphic functions.

468. Topology
(3-0-3)
Prerequisites: MATH 222 and 225 or equivalent.
An introduction to topology. Topics include the theory of surfaces, knot theory, and the theory of metric spaces.

469. Topics in Mathematical Logic
(3-0-3)
Prerequisite: MATH 126 or equivalent.
An introduction to mathematical logic. Topics include model theory, computability theory, and set theory.

471–472. Studies in Algebra
(3-0-3) (3-0-3)
Topics in algebra, number theory, and algebraic geometry.

475–476. Studies in Analysis
(3-0-3) (3-0-3)
Topics in analysis, differential equations, and measure theory.

477–478. Studies in Geometry
(3-0-3) (3-0-3)
Topics in topology, geometry and differential geometry.

497. Directed Readings
(V-0-V)
Prerequisite: Consent of director of undergraduate studies.
A high-level introduction to the theory of functions of one complex variable. Topics include analytic functions, Cauchy’s theorem, Taylor series, Laurent series, singularities, residue theory, conformal mapping, analytic continuation, Riemann surfaces, entire functions, and meromorphic functions.
Bachelor of Science with a Major in Physics.
The physics curriculum at Notre Dame consists of five course sequences or programs. These programs are designed to accommodate the academic and professional interests of the majority of physics majors. Students with alternative interests are encouraged to discuss special programs with the departmental chair.

All physics majors take the following basic sequence of courses:
- General Physics (PHYS 151, 151L, 152, 152L, 253, 253L)
- Mechanics I (PHYS 252)
- Mathematical Methods in Physics (PHYS 271, 272)
- Sophomore Seminar (PHYS 247)
- Modern Physics (PHYS 260, 361)
- Electricity and Magnetism (PHYS 356)
- Junior Seminar (PHYS 347)
- Modern Physics Lab I (PHYS 442)
- Senior Seminar I (PHYS 447)
- General Chemistry (CHEM 117, 118)
- Mathematics (MATH 125, 126, 225, or MATH 165, 166, 265, and 266)
- Physics or Mathematics three-credit elective (as defined below)

In addition to the basic sequence of courses, the following courses are required for each program.

Career Program
The Career Program is designed for students who intend to do graduate work in physics or in astronomy, or who intend to seek employment as professional physicists at the bachelor level.

In addition to the physics core courses, majors in the career program are required to complete the additional following courses:
- Thermal Physics (PHYS 352)
- Electromagnetic Waves (PHYS 357)
- Modern Physics Lab II (PHYS 443)
- Quantum Mechanics I (PHYS 453)

The other physics or mathematics three-credit elective is selected with the advisor’s consent from the following: MATH 165, 166, 265, and 266.

Physics-in-Medicine Program
Students in this program may prepare for professional schools in medicine, medical physics, biochemistry, etc., with appropriate selection of electives. In addition to the physics core courses, majors in physics-in-medicine must complete the following courses, which total 19 credit hours.

The required physics or mathematics three-credit elective for this program is to be selected with the advisor’s consent from the additional required courses for physics career majors or from the physics and mathematics three-credit elective list for the Physics Career Program.

Physics and Computing Program
Students interested in concentrating in computer science while obtaining a major in physics may choose the Physics and Computing Program. In addition to the physics core courses, these students will complete at least 15 credit hours in the Department of Computer Science and Engineering.

Applied Physics Program
In addition to the physics core courses, the Applied Physics Program requires at least 15 additional credits, to be selected with the advisor’s approval from the following. These may include any of the physics and mathematics elective courses listed above and any courses offered by the Department of Electrical Engineering that deal with electrical properties of materials. Classes include, but are not restricted to, Electrohydrodynamics I and II (EE 347 and 357), Electronic Transport Theory (EE 466) and Electronic Properties of Materials (EE 476).

### SUMMARY OF REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE IN PHYSICS

<table>
<thead>
<tr>
<th>Program</th>
<th>Career Program</th>
<th>Applied Physics</th>
<th>Physics and Computing</th>
<th>Physics in Medicine</th>
<th>Physics Education</th>
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</thead>
<tbody>
<tr>
<td>Mathematics</td>
<td>11.5–14.5</td>
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<td>11.5–14.5</td>
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<tr>
<td>Physics</td>
<td>51–54</td>
<td>36–51*</td>
<td>39–42*</td>
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<tr>
<td>Chemistry</td>
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<tr>
<td>Biology</td>
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<td>11</td>
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<tr>
<td>Language</td>
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<tr>
<td>Electrical Engineering</td>
<td>—</td>
<td>3–15</td>
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<tr>
<td>Free Electives</td>
<td>17.5**</td>
<td>17.5**</td>
<td>14.5**</td>
<td>10.5**</td>
<td>0**</td>
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<tr>
<td>Total Credit Hours</td>
<td>124</td>
<td>124</td>
<td>124</td>
<td>124</td>
<td>131.5</td>
</tr>
</tbody>
</table>

* Students must take a minimum of 60 credit hours in science.
** Or any science other than mathematics or physics.
+ Assumes intermediate-level competency in language was achieved by taking three three-credit courses.

*The physical or mathematics three-credit elective is selected with the advisor's consent from the following: MATH 425, and physics courses numbered 212, 231–299, 331–399, 403, or 431–489. Students are strongly encouraged to follow the sample curriculum that follows.

The required physics or mathematics three-credit elective for the other physics programs is to be selected with the advisor’s consent from the additional required courses for physics career majors or from the physics and mathematics three-credit elective list for the Physics Career Program.

**Physics and Computing Program**
Students interested in concentrating in computer science while obtaining a major in physics may choose the Physics and Computing Program. In addition to the physics core courses, these students will complete at least 15 credit hours in the Department of Computer Science and Engineering. Students may choose from among four standard course sequences or alternatively may, with the consent of their advisor and the chair of the CSE department, arrange an individualized course sequence. Physics 333, Numerical Methods, is a recommended physics elective for students in this program.
Physics Education Program

In addition to the physics core courses, majors in the Physics Education Program must complete the following courses, which total 33 credit hours.

(Education courses are offered at Saint Mary’s College):

EDUC 201F: Teaching in a Multicultural Society
EDUC 220. Applied Media and Instructional Technology
EDUC 350. Educational Psychology; Human Growth and Development of the Adolescent
EDUC 356. Educational Psychology: Educating Exceptional Leaders
EDUC 404. Reading in the Content Area
EDUC 449. Teaching Science in the Secondary School
EDUC 475. Student Teaching in the Secondary School (spring of senior year)

Furthermore, majors in the physics education program must complete a minimum of four additional credits selected, with the advisor's approval, from courses offered in the College of Science, outside the departments of physics and mathematics or in geological sciences.

Physics As a Second Major

The requirement for physics as a second major, for students in the colleges of engineering, arts and letters or business, consists of the physics core courses listed above, except General Chemistry. To list physics as a second major on the transcript, the student must satisfy all of the requirements for a major in some other department and college of the University.

Sample Curriculum (Career Program):

First Year

First Semester
FYC 110 3
MATH 125 4
PHYS 151, 151L 4
History or Social Science1 3
CHEM 117 4
Physical Education or ROTC 0

Second Semester
Philosophy or Theology1 3
MATH 126 4
PHYS 152, 152L 4
History or Social Science1 3
CHEM 118 4
Physical Education or ROTC 0

Sophomore Year

First Semester
PHYS 253, 253L 4
MATH 225 3.5
PHYS 271, 271T 3.5
PHYS 247 1
Language 3
Philosophy or Theology 3

Second Semester
PHYS 252 3
PHYS 260 4
PHYS 272, 272T 3.5
Language 3
Philosophy or Theology 3

Junior Year

First Semester
PHYS 352 3
PHYS 356 3
PHYS 361 4
PHYS 347 1
Language 3

Second Semester
PHYS 331 3
PHYS 333 3
PHYS 357 3
MATH 425 3
Literature or Fine Arts 3

Senior Year

First Semester
PHYS 485 3
PHYS 442 3
PHYS 447 1
PHYS 453 3
Elective 3
Philosophy or Theology 3

Second Semester
PHYS 443 3
PHYS 481 3
PHYS 454 3
Electives 6

1. The student should take three general requirement courses during the first year, including one course that is designated a University Seminar 180.

Physics Course Descriptions. The following course descriptions give the number and title of each course. Lecture hours per week, laboratory and/or tutorial hours per week, and credits each semester are in parentheses.

101–102. Concepts of Physics I and II

Prerequisite: A working knowledge of high school algebra.

A course developing the basic ideas of energy and power and their applications. The fossil fuels are considered together with their limitations, particularly as related to global warming, pollution and their nonrenewable character. The advantages and disadvantages of nuclear power are studied and compared with alternative energy sources such as solar energy, wind, and geothermal and hydroelectric power. Various aspects of energy storage and energy conservation are also considered. This course is designed for the non-specialist. It is open to first-year students only. It satisfies one semester of the University science requirement, but PHYS 104 and PHYS 204 may not both be counted toward that requirement.

104. Concepts of Energy and the Environment

Prerequisite: None.

A course emphasizing science literacy that provides the tools for a basic understanding of scientific developments and their potential consequences. Developments in many areas of science will be discussed, including biology, chemistry, mathematics, engineering, and computer science, with the view that basic physics serves as a common thread between them. Topics covered include the mechanisms of scientific discovery, the impact of scientific discoveries on society, science, and ethics, how scientific research is supported, and the tools of contemporary science. The course focuses on concepts rather than formulas and concentrates primarily on examples taken from contemporary science. Material includes the review of articles from sources such as Nature, Science, and Scientific American.

This course satisfies one semester of the University science requirement. If taken by science or engineering students, this course counts as a general elective.
110. Descriptive Astronomy

(3-0-3)

Prerequisites: Three units of high school algebra and geometry. One unit of high school science. A description of the motions and structure of the earth, moon and planets. An exposition of the modern theories of solar and stellar structure, nebulae, and galaxies. Basics of stellar evolution, black holes, quasars and other recent developments. An introduction to cosmology. This course includes elementary observational projects. The course fulfills one semester of the University science requirement.

115–116. Principles of Physics I and II

(3-0-3) (3-0-3)

Prerequisites: A knowledge of algebra and trigonometry and the ability to use them in solving problems. High school chemistry is recommended. PHYS 115 is a prerequisite to PHYS 116.

A course intended for students who desire a grounding in all the major principles of physics but who plan to major in some area other than science or engineering. The ability to apply these principles to the solution of problems is a major goal of the course. The following topics are normally included.

- Kinematics and dynamics of a particle, work, energy, momentum, harmonic motion, gravitation, and circular orbits. Wave motion, interference, standing waves, the Doppler effect. Temperature, heat, first law of thermodynamics, kinetic theory of gases. Electric charge, Coulomb's law, electric field and potential, current, resistance, DC circuits. Magnetic force, electromagnetic induction. The nature of light, the spectrum. Photons, photoelectric effect, Compton scattering, deBroglie waves, energy levels, X-rays. Nuclei and radioactivity. Special relativity. Additional material will be at the discretion of the instructor. The division between PHYS 115 and 116 will depend on the order of presentation. This course fulfills the University science requirement.

131–132. General Physics I and II

(4-1-4) (4-1-4)

Prerequisites for PHYS 131. High school chemistry and physics and three-and-one-half units of mathematics.

Corequisite for PHYS 131. MATH 125 or equivalent.

Prerequisites for PHYS 132. PHYS 131 or 151, and MATH 125.

Corequisite for PHYS 132. MATH 126 or equivalent.

A two-semester sequence in general physics. Topics include the kinematics and mechanics of a particle; work, energy and momentum, and associated conservation laws; rotation, torque and angular momentum; oscillations and wave motions; electricity, statics, electric current and circuits; magnetism, electromagnetic induction and waves; geometrical optics. A course designed for students of science and engineering. Laboratory meetings in alternating weeks only. Weekly tutorial sessions.

151–152. General Physics I-M and II-M

(4-2-4) (4-2-4)

Prerequisites for PHYS 151. High school chemistry and physics, and three-and-one-half units of mathematics.

Corequisite for PHYS 151. MATH 125 or equivalent.

Prerequisites for PHYS 152. PHYS 151 or 131, and MATH 125.

Corequisite for PHYS 152. MATH 126 or equivalent.

The first two semesters of a three-semester sequence in general physics. Topics include the kinematics and mechanics of a particle; work, energy and momentum, and associated conservation laws; rotation, torque and angular momentum; oscillations and wave motions; electrostatics, electric current and circuits; magnetism, electromagnetic induction and waves; geometrical optics. A course designed for students intending to enter the Department of Physics. Laboratory meetings each week.
171. Elementary Cosmology
(3-0-3)
Prerequisites: High school physics and algebra.
An elective course for students planning to major in the colleges of arts and letters or business. It is designed to acquaint the non-mathematically-inclined student with the most important discoveries in physics of the last few decades and how they have altered our perceptions of the origin and structure of the universe. This course examines such questions as: “Where did the universe come from?” “Why do scientists feel sure that it was born in a cosmic fireball called the Big Bang?” and “Where did the Big Bang itself come from?” This is a reading-intensive course based on popularizations of science written for the curious and intelligent layperson. The emphasis will be on class discussion of the readings. One book report and a term paper are required in addition to examinations. This course satisfies one semester of the University science requirement. If taken by science students, this course counts as general elective credit.

172. Topics in Biophysics
(3-0-3)
Prerequisites: High school physics and mathematics. This course provides an overview of how the laws of physics can be used to explain biological systems and of the physical principles that underlie modern imaging techniques (MRI, CAT, etc.). Examples to be discussed include bioelectrical processes, e.g., the heart, transport across cell membranes, and electro-sensing by eels. Vision, hearing, blood circulation, and respiration are explained as biophysical processes. The course presents principles in a descriptive manner; no previous formal study of biology is required or assumed.

For students majoring in the College of Arts and Letters or the Mendoza College of Business, this course satisfies one semester of the University science requirement. For other students, this course counts as a general elective.

174. Physics of Music and Sound Reproduction
(3-0-3)
Prerequisites: High school algebra, geometry, and trigonometry.
The physics of sound reproduction, including the acoustical and electronic production and reproduction of sound. The course will include basic Newtonian mechanics, oscillating systems, wave motion, sound, Fourier synthesis, musical acoustics of various instruments, introduction to electricity and magnetism, and the physics of microphones, loudspeakers, phonographs, tape recording, digital compact discs and electronic synthesizers. This course satisfies one semester of the University science requirement. If taken by science or engineering students, this course counts as general elective credit.

176. Technological Risk
(3-0-3)
Prerequisites: None.
A survey of risk issues in our technological society. Topics include the perception, measurement, assessment, management and politics of technological risk, together with a discussion of possible ethical bases for risk/benefit analysis. Case studies will include highway safety, air transportation, chemical carcinogenesis, fossil fuels (including global warming and ozone depletion issues), and ionizing and non-ionizing radiation (from high-level radioactive waste to electric blankets). This course is intended for students planning to major in the colleges of arts and letters or business and satisfies one semester of the University science requirement.

178. Physical Methods in Art and Archaeology
(3-0-3) Wiescher
Prerequisite: High school physics and algebra.
A course that gives an overview of the various physics-based analysis and dating techniques used in art and archaeology. The course will cover topics such as X-ray fluorescence and X-ray absorption, proton-induced X-ray emission, neutron-induced activation analysis, radiocarbon dating, accelerator mass spectrometry, luminescence dating, and methods of archeometry. Multiple examples of the use of the techniques in art and archaeology will be given, e.g., under X-ray techniques and accelerator mass spectrometry, the analysis of ancient coins and violin varnish and the Iceman and the Turin Shroud are used respectively as examples. Physics principles of the methods and techniques will be taught in a descriptive manner. This course is intended for students in arts and letters or business and satisfies one semester of the University science requirement. If taken by science or engineering students, this course counts as general elective credit.

192. Modern Physics from Quarks to Quasars
(3-0-3) Kolda
Restricted to first-year arts and letters intents in the Honors Program.
This course emphasizes themes of modern physics and will be organized around the concepts of symmetry and physical laws. For example, how do symmetries observed in nature lead to fundamental laws of conservation of energy and momentum? Examples from areas of modern physics such as cosmology and astrophysics are used to bring these topics to life. We consider questions such as: “What happens if one travels alongside a beam light?” (which leads us into special relativity); “Why is the night sky so dark?” (the big bang); “What is matter?”; “What is mass”; “What are forces?” The course is a mix of lecture, discussions, and lab/demonstrations.

204. Energy and Society
(3-0-3)
Prerequisite: A working knowledge of high school algebra.
A course developing the basic ideas of energy and power and their applications from a quantitative and qualitative viewpoint. The fossil fuels (coal, oil, natural gas) are studied together with their societal limitations (pollution, global warming, diminishing supply). Nuclear power is similarly studied in the context of the societal concerns that arise (radiation, reactor accidents, nuclear weapons proliferation, high-level waste disposal). The opportunities as well as the risks presented by alternative energy resources, in particular solar energy, wind, geothermal and hydropower, together with various aspects of energy conservation, are developed and discussed. This course is designed for the non-specialist and satisfies one semester of the University science requirement.

205. Nuclear Warfare
(1-0–1)
Prerequisite: none.
Nuclear phenomena; nuclear fission and fusion. Nuclear weapons. Effects of blast, shock, thermal radiation, prompt and delayed nuclear radiation. Fire, fallout, ozone-layer depletion, electromagnetic pulse, “nuclear winter.” Medical consequences, physical damage, effects on the individual and on society. Defensive measures and their feasibility. Scenarios for war and peace, proliferation of nuclear weapons material, recent diplomatic history. U.S. Bishops' Pastoral Letter. The course is open to all students and counts for science majors as a general elective credit.

210. Descriptive Astronomy
(3-0-3)
Prerequisites: Three units of high school algebra and geometry. One unit of high school science. A description of the motions and structure of the earth, moon and planets. An exposition of the modern theories of solar and stellar structure, nebulae and galaxies. Basics of stellar evolution, black holes, quasars and other recent developments. An introduction to cosmology. Includes elementary observational projects. The course is open to all students. It fulfills one semester of the University science requirement. The courses PHYS 110 and PHYS 210 are the same course. If taken by science or engineering students, this course counts as general elective credit.
212. Scientific Programming
(3-0-3)
Prerequisite: PHYS 152 or equivalent.
The principal goal of this course is to develop a good level of competence and experience in the use of computers as a tool for scientific studies. The course is intended primarily for physics majors. Topics covered will include (1) the FORTRAN language, (2) graphical presentation of results including user-written programs and graphics packages, (3) the use of scientific libraries of subroutines, (4) the use of other scientific programs such as algebraic manipulators, (5) the use of spreadsheets for problem solving, etc. Course-work will include the use of high-end UNIX workstations.

221–222. Physics I and II
(3-2-4) (3-2-4)
Prerequisites for PHYS 221. MATH 119 and 120, or MATH 125 and 126.
Prerequisites for PHYS 222. PHYS 221 or equivalent.
The basic principles of mechanics, fluid mechanics, thermal physics, wave motion, sound, electricity, magnetism, optics and modern physics. Primarily for students in the life sciences.

231. General Physics III
(3-1-3.5)
Prerequisite: PHYS 132 or 152, MATH 126.
Corequisite: MATH 225 or equivalent.
A third semester in general physics. Topics include (1) interference and diffraction; (2) quanta and the wave-particle duality; (3) introduction to quantum mechanics; (4) atomic, nuclear and particle physics; (5) physics of the solid state; (6) astrophysics and cosmology. A course designed for students of science and engineering. Laboratory meetings in alternating weeks only.

247. Sophomore Seminar
(1-0–1)
A discussion of current topics in physics by staff members.

252. Intermediate Classical Mechanics
(3-0-3)
Prerequisite: PHYS 253 and 271
Corequisite: PHYS 272
Newtonian mechanics of particles in one, two and three dimensions; oscillations; non inertial reference frames; gravitation, central forces; systems of particles; kinematics and dynamics of rigid body motion; Lagrangians; Hamilton’s equations.

260. Modern Physics I
(Formerly numbered 431)
(4-0-4)
Prerequisite: PHYS 253 and PHYS 271.
Corequisite: PHYS 272.

(3-1-3.5)
Prerequisite for PHYS 271. MATH 126 or equivalent
Corequisite for PHYS 271. MATH 225 or equivalent
Prerequisite for PHYS 272. Phys 271
A study of methods of mathematical physics. Topics include matrices, linear algebra (including matrices and determinants), vector and tensor analysis, vector calculus, curvilinear coordinates, series, ordinary differential equations, partial differential equations, orthogonal functions and vector spaces, special functions (including Bessel, Legendre, and Hermite), calculus of variations, Fourier series, and group theory.
Weekly tutorial sessions.
Students taking the PHYS 271–272 sequence cannot get credit for MATH 228, 230, or 325.

309. Philosophical Issues in Physics
(3-0-3)
Prerequisite: One year of general physics at the college level.
This course is intended for non-science students who desire to begin an examination of the origins of the modern laws of physics and for science students who wish to know the actual route to the discovery and the broader implications of the formal theories with which they are already familiar. The historical background to and philosophical questions associated with major laws of physics will be discussed, in large measure by examining directly relevant excerpts from the writings of some of the creators of seminal concepts and theories in physics. The latter part of the course will concentrate on historical and philosophical issues related to relativity and especially to quantum theory and its interpretation. This course is accepted as a science elective in the College of Science.

310. Topics in Astronomy and Astrophysics
(3-0-3)
Prerequisite: PHYS 222 or 231 or 253.
This course is designed to provide undergraduate science and engineering majors in any department a fundamental background in current topics of astronomy and astrophysics. Astronomy is a science that uses physics to interpret astronomical events. This field is rapidly developing. Each year brings an increased number of significant and exciting discoveries based on data from a variety of spacecraft, rockets, balloons and a whole new technology of ground-based observatories and detectors. The course will provide quantitative insights into astrophysical topics of interest such as the structure and evolution of stars, the dynamics of cosmic gases, nucleosynthesis, black holes, galaxy formation, cosmology, the missing mass problem, the size and mass of cosmic objects, the large-scale behavior of the universe, quasars, evolution of the solar system and the search for planetary systems around other stars. Each topic will be developed and evaluated along with the most recent work in these areas. This is an approved science elective.

331. Lasers and Modern Optics
(2-3-3)
Prerequisite: PHYS 231 or 253.

333. Numerical Methods
(3-0-3)
Prerequisites: PHYS 212 or a knowledge of programming, MATH 228, PHYS 272, or equivalent, and a calculus-based course in general physics.
Elements of numerical analysis: functional equations, polynomial approximations, numerical differentiation, integral analysis. Numerical solution of differential equations: first-order equations, initial value determination, applications to mechanics and electricity, eigenvalue problems for second-order linear differential equations. Elementary methods for solving partial differential equations: relaxation methods, variational methods. This course is intended primarily for physics majors but is open to students from other departments who have adequate backgrounds in mathematics and physics. Credit is not given for both PHYS 333 and MATH 318.
347. Junior Seminar

(1–0–1)
A discussion of current topics in physics by staff members.

351. Mechanics II

(Formerly numbered 251)
(3-0-3)
Prerequisite: PHYS 252.
Conservation laws for systems of particles; coupled oscillations; rotating coordinate systems; one-dimensional wave motion; gravitation; kinematics and dynamics of rigid body motion; Lagrange's equations.

352. Thermal Physics

(3-0-3)
Prerequisite or Corequisite: PHYS 361.
Physical thermodynamics, kinetic theory and an introduction to statistical mechanics.

356. Electricity and Magnetism

(3-0-3)
Prerequisites: PHYS 252 or 250, PHYS 272 or MATH 325.

357. Electromagnetic Waves

(3-0-3)
Prerequisite: PHYS 356.
Study of electromagnetic waves. Physical optics. Radiation from accelerating charges. Some topics from the special theory of relativity.

361. Modern Physics II

(4-0-4)
Prerequisite: PHYS 260.
Prerequisite or Corequisite: MATH 325.
A continuation of Modern Physics I. Topics in quantum physics. Molecular bonding and spin valence. Molecular spectra. Bonding, energy levels and band structure in solids. Ionic crystals, metals and semiconductors. Thermal, electric, magnetic and optical properties of solids. Quantum numbers of particles, basic forces, the particle zoo. Stable nuclei, nuclear structure and models, nuclear decay and reactions, energy levels, fission, fusion. Particle scattering. Production, detection and properties of elementary particles.

403. Methods of Theoretical Physics

(3-0-3)
Prerequisite: MATH 325.
A study of the methods of mathematical physics. Topics include linear vector spaces, matrices, group theory, complex variable theory, infinite series, special functions, and differential equations.

421. Medical Physics

(3-0-3)
Prerequisite: A one-year course in college physics. Topics involving the applications of physics in medicine and biology are selected from the following: external and internal forces on the body; heat and temperature equilibrium; physics of hearing; physics of vision; nerve conduction; muscle contraction; electric potentials of the brain; physics of cardiovascular and pulmonary systems; ionizing radiations and their effects; nuclear medicine; radiotherapy; physics of some biological instruments. An elective course for preprofessional students, but open to other students.

432. Biological Physics

(3-0-3)
Prerequisites: PHYS 131 and 132; or PHYS 221 and 222 and BIO161 or 201.
The functioning of cells at the molecular level will be discussed on the basis of basic physics principles including Newtonian mechanics, thermodynamics, statistical mechanics, and electrical transport. The course covers diverse topics including cell energy balance, molecular machines, nerve impulse propagation, self-assembly; electrical properties of molecules. This is an approved science elective.

442–443. Modern Physics Laboratory I and II

(1–4–3)
Prerequisite: PHYS 361.
A laboratory course stressing experiments in atomic, nuclear and solid-state physics. The course is designed to introduce the student to experiments and methods closely related to modern-day research. Students will be introduced to the fundamentals of semiconductor devices and the construction and use of such devices.

447. Senior Seminar

(1–0–1)
A discussion of current topics in physics by students and staff members.

453–454. Introduction to Quantum Mechanics I and II

(3-0-3) (3-0-3)
Prerequisite: PHYS 361.
The experimental basis for the wave picture of matter and the fundamental ideas of quantum mechanics. An elective course for senior physics majors.

471–472. Topics in Contemporary Physics I and II

(3-0-3) (3-0-3)
A treatment in depth of selected topics and problems of current interest in physics.

481. Relativity: Special and General

(3-0-3)
Prerequisite: PHYS 356, PHYS 361.
An introduction to relativity, both special and general. Special relativity: Lorentz transformations of events, geometry of space-time, relativistic kinetics (energy-momentum), Lorentz transformations of electromagnetic fields. General relativity: gravity and light, principle of general covariance, Einstein's field equations, Schwarzschild solution, precession of perihelions of planets, deflection of light, black holes.

485. Astrophysics

(3-0-3)
Prerequisites: PHYS 356, PHYS 361.
A study of the physical problems associated with stellar motions; energy generation and radiation; astronomical distances; celestial mechanics; galactic dynamics; cosmic rays; interstellar matter; thermodynamics; and equations of state of various stellar models. Observational techniques and methods of computation will be discussed. An elective course for senior physics majors and other qualified students.

497. Directed Readings

(0-V-V)
Prerequisite: Permission of department chair and individual instructor.
Study of topics not covered or only briefly covered in other courses. Readings, problems and reports. May include laboratory work not encompassed by PHYS 499.

498. Undergraduate Research

(0-V-V)
Prerequisite: Requires permission of the physics department chair and the student's department chair. Research in collaboration with members of the faculty. Three to 15 hours each week, arranged individually for each student. One to five credits. Certain graduate courses in physics are open to qualified advanced undergraduates, subject to the approval of the chair of the department. These courses are listed in the Graduate School Bulletin of Information.
Preprofessional Studies

Chair: Rev. Joseph L. Walter, C.S.C., Ph.D.
Professional Specialist: Rudolph M. Navari, M.D., Ph.D.
Assistant Professional Specialist: Rev. James K. Foster, C.S.C., M.D.

Program of Studies. The Department of Preprofessional Studies offers several programs in the two major sequences, namely the program sequence in premedical studies and the program in the College Sequence.

All of the programs are quite flexible and allow the student to design a curriculum, in consultation with the chair or the associate dean in the College of Science, in order to enable the student to enter the profession best suited for his or her talents. The program in premedical studies enables the student to obtain an excellent preparation to enter any of the professions of medicine, dentistry or the other ancillary fields of the healing professions. The interdisciplinary programs of the collegiate sequence have been designed to offer significant flexibility to prepare students for the professions of science-education, science-business, and science-computing. All of the programs allow for a strong science background while also allowing a diverse background in the arts and humanities for individuals with a desire to obtain a broad educational background.

The major goal of this department is to provide an education in the best of liberal traditions of scientific thought and analysis, which the student can utilize for career opportunities in a variety of fields.

The program sequence in premedical science studies is a special program within the Department of Preprofessional Studies for students preparing to enter the professions of medicine, dentistry, osteopathy, veterinary medicine, podiatry, optometry or several of the allied-health professions.

Notre Dame has been recognized as an accredited institution for premedical studies for more than 100 years. A proper selection of courses leading to the degree of bachelor of science will qualify the student for admission to any medical school in the world. A year before his or her expected entrance to medical school, the student takes the Medical College Admission Test, which is given twice a year at several hundred sites throughout the country, including Notre Dame. Students taking this test should have completed the basic courses in chemistry, biology and physics. The curricula leading to the degree of bachelor of science in the departments of biology and chemistry also satisfy the requirements for admission to any medical school.

Information concerning the requirements for admission to schools of medicine, dentistry, osteopathy, veterinary medicine, optometry and podiatry, as well as on several ancillary health careers, is available from the office of the Department of Preprofessional Studies, 239 Nieuwland Science Hall.

Students planning to enter the profession of dentistry will have a program of courses that will satisfy the requirements for admission to any dental school. The aptitude test administered by the American Dental Association is given at Notre Dame twice each year.

Bachelor of Science with a Major in Preprofessional Studies —
Premedical Science Sequence
(124 semester hour credits; 64 science hour credits, minimum)

First Year
First Semester
FYC 110 English Composition 3
MATH 119 4
CHEM 117 4
History or Social Science* 3
Philosophy or Theology* 3
Physical Education or ROTC —
— 17

Second Semester
Philosophy or Elective* 3
MATH 120 4
CHEM 118 4
History or Social Science* 3
University Seminar 180J* 3
Physical Education or ROTC —
— 17

Sophomore Year
First Semester
CHEM 223, Elementary
  Organic Chemistry I 3
CHEM 223L: Elementary
  Organic Chemistry Lab I 1
BIOS 201, General Biology A 3
BIOS 201L: General Biology A Lab 1
Elective 3
Language — 3
— 14

Second Semester
CHEM 224, Elementary
  Organic Chemistry II 3
CHEM 224L: Elementary
  Organic Chemistry Lab II 1
BIOS 202, General Biology B 3
BIOS 202L: General Biology B Lab 1
Elective 3
Language — 3
— 14

Junior Year
First Semester
Science Elective** (Note 3) 4
Physics (PHYS 221, 221L) 4
Language or Elective 3
Philosophy or Elective 3
Science Elective 3
— 17

Second Semester
Science Elective** (Note 3) 3
Physics (PHYS 222, 222L) 4
Electives 9
— 16

Senior Year
First Semester
Science Elective** (Note 3) 3
Science Elective** (Note 3) 4
Philosophy or Theology or 300-level English
  Literature (Note 6) 3
Electives 6
— 16

Second Semester
Science Elective** (Note 3) 4
Theology (Medical Ethics) 3
Elective 3
Science Elective** (Note 3) 3
— 13

Notes:
1. All course instruction in the curricula of the Department of Preprofessional Studies is provided by other departments in the College of Science and other colleges of the University.
2. The elective courses in the senior year may include a thesis based on laboratory work performed in a registered course in a given department with the approval of the head of that department, who will specify the number of credits assigned to the thesis.
3. The choice by the student of elective courses in science for the program in preprofessional studies will be based upon the requirements of the professional schools and upon the lists of courses suggested or recommended by those schools in which the student is interested; the choice will be based also upon the advice and counseling of the chair of the department. From the Medical and Dental School Requirements Books, the following courses, in order of frequency of appearance, would be the most highly recommended in addition to the five basic science courses, giving the student applicant the best science background to be a most attractive candidate to any school to which he or she wishes to apply: genetics, analytical chemistry, developmental biology, biochemistry, physical chemistry, physiology, cell biology, and microbiology. Additional courses in higher mathematics, statistics and computer science are recommended for qualified
<table>
<thead>
<tr>
<th>REQUIRED COURSES</th>
<th>SCIENCE-BUSINESS PROGRAM</th>
<th>SCIENCE-COMPUTING PROGRAM</th>
<th>SCIENCE-EDUCATION PROGRAM</th>
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<tr>
<td>Biological Sciences</td>
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<td>Geology/Organic Chemistry</td>
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<td>Statistics: MATH 214 or BIOS 411</td>
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<tr>
<td>Education Courses</td>
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<td>33</td>
</tr>
</tbody>
</table>

**Language Intermediate Level Competency**

| FYC 110                                              | 3                        | 3                          | 3                         |
| Philosophy*                                          | 6                        | 6                          | 6                         |
| Theology*                                            | 6                        | 6                          | 6                         |
| History*                                             | 3                        | 3                          | 3                         |

| Social Sciences                                      | 3                        | 3                          | 3                         |
| Literature/Fine Arts                                 | 3                        | 3                          | 3                         |
| Free Electives                                       | 2“                       | 12”                        | 0”                        |

**Total**                                              **24**                     **124**                     **126**

*One of these courses must be a University Seminar 180.

 Assumes Intermediate Level Competency in language was achieved by taking three three-credit courses.

4. For the selection of non-science electives for the programs, students should know that medicine and the other healing professions need individuals with a diversity of educational backgrounds and a wide variety of talents and interests. All of these schools recognize the desirability of a broad education—a good foundation in the natural sciences (mathematics, chemistry, biology and physics), highly developed communication skills and a solid background in the social sciences and humanities.

5. Recommendation 1 of the recent Report of the Association of American Medical Colleges titled “Physicians for the 21st Century” encourages a broadening of preparation. The department continues to encourage students to follow that recommendation by using the requirements of history and social science. English and the 27 general elective credits “to be an informed participant in contemporary society by understanding its politics, history and economics. To appreciate the many dimensions of human experience requires informed reflection upon the literature, the philosophy and the arts . . . of all people in our society.”

6. To fulfill the medical school requirements of two semesters of English, students are required to take FYC 110 (Composition) and one literature course taught in English. The literature course can be either a University Seminar 180 or a 300-level literature course offered by the English Department. Thus, if a student's University Seminar requirement is met by one of the 180 literature options, then the student will not be required to take 300-level literature. Note, for this major only, a course in fine arts is not acceptable for the University literature/fine arts requirement. (A fine arts course will count as a general elective.)

7. In the curriculum for the program, there are listed the several courses required for the degree, including one semester each of history and social science, a course in literature, two courses in philosophy and two courses in theology. Students should remember that none of the required courses can be taken as a pass/fail option.

8. Students who have completed only six hours of mathematics in the first year of studies may transfer into the program but they will be required to complete a mathematics sequence equivalent to MATH 119, 120 or MATH 125, 126. Students having taken MATH 105, 106 (or 108 or 110) may do this by taking MATH 120, while those who have taken only one semester of lower-level calculus should take both MATH 119, 120. Those students should see also the discussion on degree credit found later in this section of the Bulletin.

9. PHYS 131–132 or PHYS 151–152 may be substituted for PHYS 221–222.

10. Undergraduate Research (BIOS 498), Teaching Practicum (BIOS 495), and Directed Readings (BIOS 497) count toward the 64-hour preprofessional studies major science requirement; however, a maximum of two credits a semester and a combined total of six credit hours may be counted in fulfilling the 64-credit-hour science requirement as well as the maximum credit hours counted toward graduation.

11. All students are welcome to join the Preprofessional and/or Premedical Clubs. In addition, premedical students are encouraged to join AMSA, the American Medical Student Association.

12. All students who have had previous exposure to language will be required to take a placement examination in that language for placement in the proper course if the student wishes to continue in that language for the college requirement. If a student wishes to take a new language, of course, he or she must start from the beginning.

13. Interested parties may obtain additional information including various statistics from the department Web page. See www.science.nd.edu/ under Preprofessional Studies.
SUMMARY OF REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE
IN PREPROFESSIONAL STUDIES

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
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<td>Biological Sciences</td>
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<tr>
<td>Chemistry</td>
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<tr>
<td>Mathematics</td>
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<td>Physics</td>
<td>8</td>
</tr>
<tr>
<td>FYC 110</td>
<td>3</td>
</tr>
<tr>
<td>Language Intermediate-Level Competency Philosophy</td>
<td>6</td>
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<tr>
<td>Theology</td>
<td>6</td>
</tr>
<tr>
<td>History</td>
<td>3</td>
</tr>
<tr>
<td>Social Science</td>
<td>3</td>
</tr>
<tr>
<td>Literature (University Seminar 180J or 300-level English; see note 6)</td>
<td>3</td>
</tr>
<tr>
<td>Science Electives</td>
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<tr>
<td>General Electives</td>
<td><strong>27</strong></td>
</tr>
<tr>
<td></td>
<td>124</td>
</tr>
</tbody>
</table>

* One of these courses must be a University Seminar 180, and 180J is recommended. See note 6.
** Assumes Intermediate-Level Competency in Language was achieved by taking three three-credit courses.

Preprofessional Studies Course Descriptions. The following course descriptions give the number and title of each course. Lecture hours per week, laboratory and/or tutorial hours per week, and credits each semester are in parentheses.

101. Medical Science from Birth to Death
(3-0-3) Foster
The course will cover the science behind the technological advances used in various medical subspecialties that raise ethical questions from the beginning to the end of life. It will provide students with an overview of the biotechnological advances that are in the news, reshaping the scientific culture of modern medicine, and challenging personal and societal human values. This course fulfills one semester of the University Science requirement. First-year students only. Fall and spring.

102. Introduction to Common Medical Illnesses
(3-0-3) Navari
The course will begin with an introduction to human anatomy in which organ structure and function will be emphasized. This will be followed by the anatomy, biochemistry, physiology and pathology of several common medical illnesses in the North American population. This course fulfills one semester of the University science requirement. First-year students only. Students may not take both this course and BIOS 106. Spring.

300. Introduction to Clinical Ethics
(3-0-3) Foster
Permission required.
The focus of the course will be an examination of the discoveries in science and medicine over the last 30 years that have challenged traditional values and ethical norms. It will include a sketch of the most recent advances in the various fields of medicine, followed by an examination of the ethical questions they raise and how they have affected the physician-patient relationship. Note: This course counts as a general elective. Fall and spring.

311. Introduction to the American Health Care System
(3-0-3) Navari
For SCPP, SCBU, ALPP, BIOS, BCHM majors.
Others, by permission.
The course will begin with a short history of the American health care system and will be followed by a discussion of the major components of the system (patients, providers, payers), health insurance coverage, managed care programs, the movement for quality health care, physicians in the changing medical marketplace, health care expenditures, and academic medical centers. This course counts as a general elective. Fall and spring.

397. Directed Readings
(1-0-1) Foster
Permission required.
Readings focus on learning how patients, families, and healthcare professionals experience illness and healing, how the stories that patients tell become the basis for diagnosis and therapeutic response, what it’s like to go through medical training and grow in identity as a physician, and the nature of the doctor-patient relationship and how it is changing. Spring.
Note: This course counts as a general elective.

Collegiate Sequence Programs
The three Collegiate Sequence programs, Science-Business, Science-Computing, and Science-Education, were instituted in 1987. These three programs allow students to obtain a strong science background while simultaneously preparing them for professions in business, computing or education.

Science-Business Collegiate Sequence
The Science-Business Collegiate Sequence in the Department of Preprofessional Studies is an individualized course of study which incorporates courses from the basic areas of business along with the four basic areas of science. This approach enables students to attain a diversified background to enter an M.B.A. program, leading to a position primarily in the scientific or health professions business areas. It is also a complete and sufficient program to enable the B.S. graduate of the sequence to enter the scientific business market immediately upon graduation.

Information on the areas of public health and hospital administration, as well as the business needs of the pharmaceutical, biological and chemical industries are available in the office of the Department of Preprofessional Studies, 239 Nieuwland Science Hall.

The other departments in the College of Science as well as the colleges of arts and letters and business administration provide all course instruction in the curricula of the Science-Business Collegiate Sequence.

Bachelor of Science with a Major in Science-Business
All Science-business majors take the following basic sequence of science courses:
- General Biology (BIOS 201–202 and 201L and 202L)¹
- General Chemistry (CHEM 117–118)¹
- Physical Geology (ENVG 231) and Historical Geology (ENVG 232)
- OR
- Physical Geology (ENVG 231) and Organic Chemistry I and Lab (CHEM 223, 223L)
- OR
- Calculus (MATH 119–120 or 125–126)¹²
- Physics (PHYS 221–222)³
- Statistics (MATH 214 or BIOS 411)

They also are required to take 20–21 credits of science electives,³ completing a minimum of 64 credits of science courses.

Also required for the major are the following business and economics courses:
- Introduction to Economics (ECON 101 or 201)¹⁴
- Accounting and Accountancy I (ACCT 231)
- Business Finance (FIN 231)
- Introduction to Management (MGT 231)
- Introduction to Marketing (MARK 231)

One business elective chosen from the following:
- ACCT 232
- FIN 360
- FIN 361
- MGT 350
- MGT 473
- MARK 370

Requirements for the program are summarized in the table above.

Notes:
1. Equivalent or higher-level sequences in science may be substituted, e.g., CHEM 113–114 or CHEM 125–126 for CHEM 117–118 or BIOS 161–162 for BIOS 201–202 or MATH 165–166 for MATH 125–126.
2. Students who have completed only six hours of mathematics in their first year may transfer into the program, but they will be required to complete a mathematics sequence equivalent to MATH 119, 120 or MATH 125,126. Students having taken MATH 105, 106 (or 108 or 110) may do this by taking MATH 120, while those who have taken only one semester of lower-level calculus should take both MATH 119, 120. (See also the discussion on science degree credit, found later in this section of the Bulletin.)
3. PHYS 131–132 or PHYS 151–152 may be substituted for PHYS 221–222.
4. The choice by the student of the elective courses in science for the program will be discussed with the student and will be based on the future industrial or health professions business interests of the student. Any major-level College of Science courses (i.e., those taken to meet science-major requirements and not those designated as “Recommended University electives”) and that are not being used to fulfill other specific graduation requirements can be used to satisfy the “Science Elective” requirement. Major-level geology courses crosslisted as science courses may be taken as science electives. Students are restricted to no more than two credits per semester (six total) for science credit and three credits per semester (nine total) for graduation credit of courses such as Undergraduate Research or Directed Readings. Teaching Practicum (BIOS 495) may not be used as a science elective.

5. The economics requirement for this major is fulfilled by taking Introduction to Economics either in the first year (ECON 101) or in the sophomore year (ECON 201). Students who have taken ECON 123/223 (Principles of Economics I) or ECON 224 (Principles of Economics II) will fulfill this requirement. Note: The course ECON 180 (Social Science University Seminar) will not fulfill the economics requirement for this major.

6. For this major, the University social science requirement will be fulfilled by the required economics course. Additional social science courses are recommended and will count toward the student’s general electives.

Suggested Curriculum for the Degree of Bachelor of Science in the Science-Business Collegiate Sequence (124 semester hour credits: 64 science hour credits, minimum)

First Year

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<th>Semester</th>
<th>Course Code</th>
<th>Course Name</th>
<th>Credits</th>
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<td>First</td>
<td>CHEM 117</td>
<td>General Chemistry</td>
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<td>MATH 119 or 125. Calculus (Note 4)</td>
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<tr>
<td></td>
<td>FYC 110</td>
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<tr>
<td></td>
<td>Theology*</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>History*</td>
<td></td>
<td>3</td>
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<tr>
<td></td>
<td>Physical Education/ROTC</td>
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</tr>
<tr>
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<td><strong>Total</strong></td>
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Second Semester

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<tbody>
<tr>
<td>CHEM 118</td>
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<td>MATH 120 or 126. Calculus</td>
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<tr>
<td>Fine Arts or Literature*</td>
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<tr>
<td>Philosophy*</td>
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Sophomore Year

First Semester

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<td>BIOS 201L</td>
<td>General Biology A Lab</td>
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<td>ENVG 231</td>
<td>Physical Geology or</td>
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<td>Language*</td>
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Second Semester

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Junior Year

First Semester

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<tr>
<td>PHYS 221, General Physics I</td>
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<td>ACCT 231</td>
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<td>Elective or Language*</td>
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Second Semester

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<td>PHYS 222, General Physics II</td>
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<td>MARK 231</td>
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<td>Elective</td>
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Senior Year

First Semester

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<td>Elective</td>
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Second Semester

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<td>Electives</td>
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<td>Business elective</td>
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*One of these courses must be a University Seminar 180.

Science-Computing Collegiate Sequence

The Science-Computing Collegiate Sequence in the Department of Preprofessional Studies is an individualized course of study which incorporates courses from the four basic areas of science along with a sequence of computing courses. The program will give the student working knowledge of various computer languages and experience using current computer technology. By choosing science electives appropriately, the student has the option of focusing in an area in science of particular interest. Graduates of this program earn a B.S. degree and are able to enter the scientific computing job market immediately upon graduation.

The other departments in the College of Science as well as the colleges of arts and letters and engineering provide all course instruction in the curricula of the Science-Computing Collegiate Sequence.

Bachelor of Science with a Major in Science-Computing

All Science-computing majors take the following basic sequence of science courses:

- General Biology (BIOS 201-202 and 201L and 202L)
- General Chemistry (CHEM 117–118)
- Physical Geology (ENVG 231) and Historical Geology (ENVG 232)
- Physical Geology (ENVG 231) and Organic Chemistry I and Lab (CHEM 223, 223L)
- Organic Chemistry I and II and Labs (CHEM 223-224, 223L-224L)
- Calculus (MATH 119–120 or 125–126) 1,2
- Physics (PHYS 221-222) 3
- Statistics (MATH 214 or BIOS 411)

They also are required to take 20–21 credits of science elective, 4 completing a minimum of 64 credits of science courses.

Also required for the major is one of the following approved sequences in computing:

Software design option:
- Advanced Programming (CSE 232)
- Discrete Mathematics (CSE 210)
- Data Structures (CSE 331)
- Fundamentals of Computing I or II (CSE 211 or 212)
- Database Concepts (CSE 346)

Theory option:
- Advanced Programming (CSE 232)
- Discrete Mathematics (CSE 210)
- Data Structures (CSE 331)
- Automata (CSE 411)
- Algorithms (CSE 413)

Theory and compilers option: 5
- Advanced Programming (CSE 232)
- Discrete Mathematics (CSE 210)
- Data Structures (CSE 331)
- Automata (CSE 411)
- Compilers (CSE 443)

Computer architecture option:
- Advanced Programming (CSE 232)
- Logic Design and Sequential Circuits (CSE 221)
- Computer Architecture I (CSE 321)
- Computer Architecture II (CSE 322)

The advisor must approve any deviations from one of these sequences.

Requirements for the program are summarized in the table.
Notes:
1. Equivalent or higher-level sequences in science may be substituted, e.g., CHEM 113–114 or CHEM 125–126 for CHEM 117–118 or BIOS 161–162 for BIOS 201–202 or MATH 165–166 for MATH 125–126.
2. Students who have completed only six hours of mathematics in their first year may transfer into the program, but they will be required to complete a mathematics sequence equivalent to MATH 119, 120 or MATH 125, 126. Students having taken MATH 105, 106 (or 108 or 110) may do this by taking MATH 120, while those who have taken only one semester of lower-level calculus should take both MATH 119, 120. (See also the discussion on science degree credit found later in this section of the Bulletin.)
3. PHYS 131–132 or PHYS 151–152 may be substituted for PHYS 221–222.
4. The choice by the student of the elective courses in science for the Science-computing program will be based on the student’s scientific interest as developed during his or her studies of the four basic areas of science. Any major-level College of Science courses (i.e., those taken to meet science-major requirements and not those designated as “Recommended University electives”) and that are not being used to fulfill other specific graduation requirements can be used to satisfy the “Science Elective” requirement. Major-level geology courses crosslisted as science courses may be taken as science electives. Students are restricted to no more than two credits of courses such as Undergraduate Research or Directed Readings in the science elective total. Teaching Practicum (BIOS 495) may not be used as a science elective.

Suggested Curriculum for the Degree of Bachelor of Science in the Science-Computing Collegiate Sequence (124 semester hour credits: 64 science hour credits, minimum)

First Year

First Semester
CHEM 117. General Chemistry 4
MATH 125. Calculus (Note 5) 4
FYC 110 3
Theology* 3
History* 3
Physical Education/ROTC 1

Second Semester
CHEM 118. General Chemistry 4
MATH 126. Calculus 4
Fine Arts/Literature* 3
Philosophy* 3
Social Science* 3
Physical Education/ROTC 1

Sophomore Year

First Semester
BIOS 201. General Biology A 3
BIOS 201L: General Biology A Lab 1
ENVG 231. Physical Geology
or
CHEM 223, 223L (Organic Chemistry I) 4
Language 3
CSE 211 (Fundamentals of Computing I) 4

Second Semester
BIOS 202. General Biology B 3
BIOS 202L: General Biology B Lab 1
Historical Geology (ENVG 232)
or
CHEM 224, 224L (Organic Chemistry II) 4
Language 3
Elective 3

Junior Year

First Semester
Science Elective 4
CSE 232. Advanced Programming 3
PHYS 221. General Physics I 4
Theology 3
Elective (or Language) 3

Second Semester
BIOS 411. Biostatistics or MATH 214. Statistics 4 (3)
PHYS 222. General Physics II 4
Electives 6
Philosophy 3

Senior Year

First Semester
Science Electives 8
CSE 331. Data Structures 3
CSE 210. 3
Electives 3

Second Semester
Science Electives 8
CSE 346. Database Concepts 3
Electives 3

* One of these must be a University Seminar 180.

Science-Education Collegiate Sequence

The Science-Education Collegiate Sequence in the Department of Preprofessional Studies is an individualized course of study which incorporates many courses from the four basic areas of science along with education courses that most states require to give the student the background necessary to receive a certificate to teach in a secondary education system. Information concerning the requirements for secondary education in the various states, as well as the general course requirements for a certificate necessary to teach science in a secondary education program, is available in the College of Science office, 174 Hurley Hall.

The other departments in the College of Science and the other colleges of the University, as well as the Education Department at Saint Mary’s College, provide all course instruction in the curricula of the Science-Education Collegiate Sequence.

Bachelor of Science with a Major in Science-Education

All Science-Education majors take the following basic sequence of science courses:
General Biology (BIOS 201–202 and 201L and 202L)
General Chemistry (CHEM 117–118)
Physical Geology (ENVG 231) and Historical Geology (ENVG 232)
OR
Physical Geology (ENVG 231) and Organic Chemistry I and Lab (CHEM 223, 223L)
OR
Organic Chemistry I and II and Labs (CHEM 223–224, 223L–224L)
Calculus (MATH 119–120 or 125–126)1, 2
Physics (PHYS 221–222)

They also are required to take 20 credits of science electives, completing a minimum of 60 credits of science courses.

Also required for the major are the following education courses taught by Saint Mary’s College:
EDUC 201. Teaching in a Multicultural Society
EDUC 220. Applied Media and Instructional Technology
EDUC 345. Curriculum and Assessment in the High School Setting
EDUC 346. Instructional Strategies and Classroom Management in the High School Setting
EDUC 350. Educational Psychology: Human Growth and Development of the Adolescent
EDUC 356. Educational Psychology: Educating Exceptional Learners
EDUC 449. Teaching Science in the Secondary School
EDUC 475. Student Teaching in the Secondary School (spring of senior year)

The education courses are those required in the State of Indiana but are also those that are required most often by the educational accrediting agencies of most states. The practical teaching experience which is required will also be arranged through the Education Department at Saint Mary’s College.

Requirements for the program are summarized in the table found two pages back.

Notes:
1. Equivalent or higher-level sequences in science may be substituted, e.g., CHEM 113–114 or CHEM 125–126 for CHEM 117–118 or BIOS 161–162 for BIOS 201–202 or MATH 165–166 for MATH 125–126.
2. Students who have completed only six hours of mathematics in their first year may transfer into the program, but they will be required to complete a mathematics sequence equivalent to MATH 119, 120 or MATH 125, 126. Students having taken MATH 105, 106 (or 108 or 110) may do this by taking MATH 120, while those who have taken only one semester of lower-level calculus should take both MATH 119, 120. (See also the discussion on science degree credit found on page 303.)

3. PHYS 131–132 or PHYS 151–152 may be substituted for PHYS 221–222.

4. The choice by the student of the elective courses in science for the science-education program will be based upon the requirements and list of courses suggested by the various state educational systems. Since the timing of the course work is particularly constrained for this major, the student should work closely with his or her advisors: an associate dean in the College of Science and an assigned advisor in the Education Department at Saint Mary’s College.

5. Any major-level College of Science courses (i.e., those taken to meet science-major requirements and not those designated as “Recommended University electives”) and that are not being used to fulfill other specific graduation requirements can be used to satisfy the “Science Elective” requirement. Major-level geology courses crosslisted as science courses may be taken as science electives. Students are restricted to no more than two credits of courses such as Undergraduate Research or Directed Readings in the science elective total. They may count up to six credits of Teaching Program (BIOS 495) in the science elective total.

**Suggested Curriculum for the Degree of Bachelor of Science in the Science-Education Collegiate Sequence (124 semester hour credits: 60 science hour credits, minimum)**

**First Year**

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<th>Course Title</th>
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<tr>
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<td>CHEM 177. General Chemistry</td>
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<td>MATH 119 or 125. Calculus (Note 6)</td>
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<td>Theology*</td>
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<td>History*</td>
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| Total | 17 |

**Second Semester**

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<td></td>
<td>MATH 120 or 126. Calculus</td>
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<td></td>
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<td></td>
<td>Philosophy*</td>
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<td></td>
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<tr>
<td></td>
<td>Social Science*</td>
<td>3</td>
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</tr>
<tr>
<td></td>
<td>Physical Education</td>
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| Total | 17 |

**Sophomore Year**

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<td>BIOS 201. General Biology A</td>
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<td>BIOS 201L: General Biology A Lab</td>
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<td>ENVG 231. Physical Geology or CHEM 223, 223L (Organic Chemistry I)</td>
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<td>Education 201F (SMC)</td>
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| Total | 17 |

**Second Semester**

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<td>BIOS 202L: General Biology B Lab</td>
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<td></td>
<td>Historical Geology (ENVG 232) or CHEM 224, 224L (Organic Chemistry II)</td>
<td>4</td>
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<tr>
<td></td>
<td>Language</td>
<td>3</td>
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<td></td>
<td>Fine Arts/Literature</td>
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<tr>
<td></td>
<td>EDUC 220 (SMC)</td>
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| Total | 17 |

**Junior Year**

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<td>EDUC 345 (SMC)</td>
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<td>EDUC 356 (SMC)</td>
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| Total | 16 |

**Second Semester**

<table>
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<td>PHYS 222. General Physics II</td>
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<td>Science Electives</td>
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<td></td>
<td>EDUC 350 (SMC)</td>
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<td></td>
<td>EDUC 346 (SMC)</td>
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| Total | 18 |

**Senior Year**

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
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<td></td>
<td>Science Electives</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EDUC 449 (SMC)</td>
<td>3</td>
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<tr>
<td></td>
<td>Philosophy</td>
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<tr>
<td></td>
<td>Theology</td>
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| Total | 15 |

**Second Semester**

<table>
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<tr>
<td></td>
<td>EDUC 475 (SMC)</td>
<td>12</td>
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</table>

| Total | 12 |

*One of these must be a University Seminar 180.

**Special Programs**

**DOUBLE MAJORS IN SCIENCE**

In certain instances, students have the option of pursuing majors in two departments in the College of Science. Combinations that are normally approved include: Biological Sciences with Chemistry, Biological Sciences with Mathematics, Biological Sciences with Physics, Biochemistry with Mathematics, Biochemistry with Physics, Chemistry with Mathematics, Chemistry with Physics, Environmental Sciences (first major) with Mathematics, and Mathematics with Physics. Examples of combinations that are normally forbidden include: Preprofessional Studies and any of the Collegiate Sequence majors with one another or with any other science major, parallel subprograms such as Mathematics and Life Sciences with Physics in Medicine and either of those with Biological Sciences or Biochemistry. All requirements of each major must be met, with no exceptions. Failing to complete a required course terminates that major for a student. Every student who wishes to major in two departments in the College of Science must prepare an agenda of specific courses to be taken, which both advisors and the dean must approve. This should be done as early as possible, but absolutely no later than the seventh day of the senior year. In certain instances, a student may possibly receive approval of a normally forbidden combination of majors, but only if a specific program has been set up by the seventh day of the sophomore year.

All double major programs in science are extremely challenging programs that require that the student take four or five science courses at a time. Thus, only students of superior scholastic ability should consider this as an option.

Students are warned that it is almost certain that completing a double major in two sciences will require total credits well over the college minimum of 124. Conflicts in scheduling of required courses may occur; neither the college nor the departments undertake to reschedule courses for the sake of double majors. For these reasons, it must be emphasized that completing a double major may well require more than four years. Only one degree is awarded (degrees in science do not specify a field).
Dual Degree Program with the Mendoza College of Business

Coordinators:
Hayden Estrada
Director of Admissions
Master of Business Administration Program
Mitchell R. Wayne
Associate Dean
College of Science

Program of Studies. The dual degree five-year program in the Mendoza College of Business and the College of Science enables the student to earn the master of business administration and bachelor of science degrees in a major in one of the five undergraduate departments in the College of Science.

This program, instituted in 1994, offers students the opportunity to better integrate studies in science and in management. The student completing this program will have a background in management as well as the first professional degree in one of the undergraduate majors of the College of Science. Because it is a demanding program, only those students of superior scholastic ability who have the aptitude, motivation and maturity necessary for the combined graduate and undergraduate program should apply. Those with outstanding internship experiences in business will be looked upon favorably. Advisors for the program are available for consultation about the advisability of applying for the program and about meeting the particular needs of students pursuing this program.

The program is open only to those currently enrolled Notre Dame students who have completed three years of an undergraduate science major first. Students interested in making application for the M.B.A./Science program should apply to the M.B.A. program during their junior year. They should take the GMAT by December of their junior year. All candidates must schedule a personal interview as a part of the M.B.A. admissions process. Students must also declare their intentions to the dean's office in the College of Science and request that a dean's eligibility letter be sent to the M.B.A. Office for them.

An applicant who is not admitted to the dual degree M.B.A./Science program continues in the undergraduate program and completes his or her science major in the usual four-year period.

As a general guide, it is expected that a student accepted to this program will take two courses for the undergraduate degree during the summer session following his or her junior year. Every dual-degree student is also expected to participate in the orientation for the M.B.A. program. This program will occupy the entire day for the two weeks prior to the first day of classes. Orientation is mandatory for all students beginning the M.B.A. program.

The following schedule of classes is an example of how an M.B.A./Science program might be accomplished.

First year, sophomore year, junior year:
As outlined for individual science major program in this Bulletin.

Summer Session following junior year:
General requirements or electives 6
MBA 503. Excel Workshop* 0
MBA 504. Career Development* 0
Accounting Review Workshop* 0
Math Review Workshop* 0

Senior Year
First Semester
MGT 500. Statistics 3
ACCT 500. Accounting 3
FIN 510. Microeconomic Analysis 3
MBA 500. Management Communication I 1.5
Undergraduate: Science/general requirements 3–7

Second Semester
FIN 500. Financial Management 3
FIN 515. Global Macroeconomic Environment 3
MGT 515. Operations Management 3
MBA 501. Management Communication II 1.5
Undergraduate: Science/general requirements 4–7

Fifth Year
First Semester
MGT 510. Organizational Behavior 3
MARK 500. Marketing Management 3
MBA: Business Ethics Elective 3
MBA: International Business elective 3
Undergraduate: Science/general requirements 3–6

Second Semester
MGT 519. Corporate Strategy and Planning 3
MBA electives 12
Undergraduate: general requirements 3–6

* Occurs during August orientation.

Total: 172 semester hours (124 undergraduate, 48 M.B.A.)

Students involved in the M.B.A./Science program will complete their undergraduate program while completing M.B.A. requirements. M.B.A. course work will not apply to the undergraduate degree. Sample schedules for particular majors are available from advisors or the dean's office. Students who are behind in the completion of their major requirements are strongly recommended to obtain permission and advising before applying to the joint program.

Nondepartmental Courses

Director:
Mitchell R. Wayne
Associate Dean
College of Science

Course Descriptions. The following course descriptions give the number and title of each course. Lecture hours per week, laboratory and/or tutorial hours per week and credits each semester are in parentheses. Note: ENVG 231, 232, 242, 362, 403, and 457 are taught by the Department of Civil Engineering and Geological Sciences.

101. The Cosmos, the Earth, and the Genome
(3-0-3) Team taught by BIOS, ENVG, and PHYS
An introduction to the evolution of our universe, from the Big Bang to the human genome. The course will cover major concepts of cosmology, earth science, and evolutionary biology. Emphasis will be placed on not only our current understanding of these fields, but how our understanding itself has evolved over time. This course fulfills one semester of the University science requirement. If taken by science or engineering students, this course counts as a general elective credit.

112. Environmental Geosciences
(3-0-3) Fein
Prerequisites: CHEM 117 or CHEM 113
This course introduces the student to earth processes and focuses on how these processes affect people, and how people affect these processes. The course explores the interactions between Earth's biosphere, geosphere, atmosphere, and hydrosphere, with the objective of demonstrating how our physical environment is controlled by geological, biological, and human forces.

212. Environmental Geosciences
(3-0-3) Fein
Prerequisites: CHEM 117 or CHEM 113
This course introduces the student to earth processes and focuses on how these processes affect people, and how people affect these processes. The course explores the interactions between Earth's biosphere, geosphere, atmosphere, and hydrosphere, with the objective of demonstrating how our physical environment is controlled by geological, biological, and human forces. SC 112 and SC 212 are the same course.

231. Physical Geology (Lecture and Laboratory)
(3-2-4) Neal
Prerequisite: Open to engineering and science common core intents.
An introduction to the Earth, its processes, composition, evolution, and structure. The course introduces students to mineralogy, petrology, structural geology, oceanography, surficial processes, geophysics, environmental geology, geobiology, and paleontology. Lecture and laboratory meetings.
232. Historical Geology (Lecture and Laboratory)  
(3-2-4) Rigby  
Prerequisite: ENVG 231 or ENVG 131, consent of instructor.  
This course introduces the student to the concept of geologic time, absolute and relative dating, earth processes and features through time, the major features of evolution, and distribution of fossils. Lecture and laboratory meetings. One-day field trip is required.

242. Mineralogy and Optical Mineralogy  
(3-2-4) Burns  
Prerequisite: CHEM 118, ENVG 231, or ENVG 131.  
Crystallography and mineral optics—physical and chemical mineralogy—its application to mineral identification in hand specimen and using the petrographic microscope.

357. Sedimentation and Stratigraphy  
(3-2-4) Rigby  
Prerequisite: ENVG/SC 242 or permission of the instructor.  
Sedimentary environments from a physical, biological, and tectonic perspective are explored, along with processes such as lithification. Identification of sedimentary rocks and interpretation of the succession of layered rocks in North America are emphasized.

403. Geochemistry  
(3-0-3) Fein  
Prerequisite: CHEM 116, 117; MATH 125, 126; or consent of instructor.  
An introduction to the use of chemical thermodynamics, and chemical kinetics in modeling geochemical processes. Special emphasis is placed on water-rock interactions of environmental interest.

459. Paleontology  
(2-3-3) Rigby  
Prerequisite: SC/ENVG 232 or consent of instructor.  
The fossil record—morphology, taxonomy, evolution, statistical population systematics, and paleoecology. One-day field trip is required.

491. Current Topics in Environmental Science  
(3-0-3) Taught by the director of the ES major.  
Environmental sciences first and second majors only.  
The course will be divided into various modules taught by experts on campus. The modules will include environmental law, risk assessment, environmental ethics, advancements in environmental and ecological science, current topics of national interest in environmental science and others. This course is required of all first majors and recommended of all second majors. Spring.

494. Senior Honors Colloquium  
(1-0-1) Hahn, Delaney  
Permission required.  
A required seminar course for seniors in the Arts and Letters/Science Honors Program. In this seminar, selected readings are assigned, and teams of students prepare and lead discussions of the readings.

495. Science in the Classroom  
(V-V-1) Staff  
Permission required.  
This course provides an opportunity for students to apply their science background in the community. Students interested in education after graduation will benefit from this course. Students will work with faculty, teachers and others, improving the science content of local elementary and middle school curricula. Science majors should note that this course counts as an activity course and not as a science elective.

498. Research Experience for Undergraduates  
(0-V-0) Staff  
Times and inclusive dates variable depending on specific program elected by the student. By permission of the dean or the director of the Summer Session only.

Science Degree Credit

Courses are generally taken in the College of Science for one of three reasons: (1) for students in either the College of Arts and Letters, or the Mendoza College of Business, or the School of Architecture, to fulfill a University requirement; (2) for students in either the College of Engineering or the College of Science to fulfill a college requirement; and (3) for students in the College of Science, to fulfill a major requirement. As a result, the College of Science offers different sequences of courses which overlap considerably in content but not level. Thus it is possible for a student who has changed his or her college or major to have taken two courses which overlap in content. Both courses will appear on the student’s transcript, but only one will count for degree credit.

As a guideline for the student and the student’s advisors, listed below are the groups of courses that overlap considerably in content. (Courses within the same group are shown in the same row and are also enclosed within parentheses; courses listed within the same column generally show a typical normal progression through course work.) In every case, only one course per group should be counted for degree credit. Generally, only the course taken last should be counted. Students and advisors are warned not to use these groups when moving between course sequences but rather to seek advice from the offering department or the College of Science office. For overlap with courses no longer taught in the year of publication of this Bulletin, please refer to previous editions of this Bulletin.

### Biological Sciences

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<tr>
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### Chemistry and Biochemistry

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### Mathematics

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Note also that no degree credit is given to any students for MATH 101; additionally, science majors will not receive degree credit for MATH 104 or MATH 107.
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