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# Chemistry

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The Department of Chemistry (<http://academics.holycross.edu/chemistry>) is counted among the nation's top producers of chemistry graduates certified by the American Chemical Society. The Chemistry curriculum provides students with a solid background in fundamental principles and theories of chemistry with hands-on experience using state-of-the-art laboratory equipment. Students gain experience and knowledge in all the major areas of modern chemistry including organic, analytical, physical, inorganic, and biochemistry and have an opportunity to focus their program on a particular area of chemistry through research and elective courses. The overall curricular program is laboratory intensive, beginning with the Discovery Chemistry Core courses in general and organic chemistry. These courses use a guided inquiry approach, in which fundamental concepts are first encountered in the laboratory and subsequent lecture sessions are used to discuss and elaborate on the laboratory experience. Advanced courses build on this firm foundation, continuing to develop the skills and knowledge needed to become effective scientists and independent researchers. The program develops the verbal and written communication skills of students by emphasizing the importance of clarity in laboratory reports and oral presentations or poster (required of all students who elect to do research).

A major strength of the Department is its undergraduate research program. Qualified students, working in association with faculty members, have an opportunity to conduct research in a wide range of chemistry fields during the academic year through one or more research courses (Chemistry 389, 390, 405/406, 407/408 and 410). Also, summer research positions with monetary stipends are usually available on a competitive basis. Involvement in a significant research project is strongly recommended for those majors interested in attending graduate school for an advanced degree in chemistry.

## The Chemistry Major

Chemistry majors are required to successfully complete nine chemistry courses with six required labs as described below. Chemistry majors also must take the first semester of physics with lab (General Physics 1 or General Physics in Daily Life 1) and Calculus through Math 134 or 136, normally by the end of the second year.

All Chemistry majors must begin with the Discovery Chemistry Core, which includes Atoms and Molecules (CHEM 181), Organic Chemistry 1 (CHEM 221), Organic Chemistry 2 (CHEM 222), and Equilibrium and Reactivity (CHEM 231). Each of these courses includes lab and they are typically taken in the order listed above during the first and second year. The path to the major normally continues with Instrumental Chemistry and Analytical Methods (CHEM 300) followed by Quantum

Mechanics and Spectroscopy (CHEM 335). CHEM 300, which introduces experimental and instrumental methods essential to modern chemistry, is considered a gateway course to the upper level of the curriculum. Each course integrates lecture and lab. Majors complete their chemistry curriculum with two advanced courses, chosen from Biochemistry (CHEM 301 or BIOL 301), Chemical Thermodynamics (CHEM 336), and Inorganic Chemistry (CHEM 351), and with one other non-research CHEM elective at the 300-level. Premedical or pre dental students wishing to complete a B.A. in chemistry are reminded that a second semester of physics, with lab, is required for both the premedical and pre dental programs.

**American Chemical Society (ACS) Certification.** Students wishing to receive ACS certification for their degree must complete the four courses in the Discovery Chemistry Core, as well as CHEM 300, CHEM 301 or BIOL 301, CHEM 335, CHEM 336, CHEM 351, and a non-research CHEM elective at the 300-level. Students must also take one half-semester lab chosen from either Biochemistry Lab (BIOL 303 or BIOL 304) or Inorganic Chemistry Lab (CHEM 352). Additionally, two semesters of 400-level research along with a comprehensive research report are required. To receive certification, Chemistry Majors must also take two semesters of physics with lab (General Physics 1 and 2 or General Physics in Daily Life 1 and 2) and Calculus through Math 134 or 136.

## Departmental Honors Program

To graduate with Department Honors a student must have completed the courses required for ACS certification, obtained a minimum GPA of 3.40 in CHEM courses as reported by the Registrar, taken two additional courses (which could include research courses), performed a significant quantity and quality of research as determined by the research advisor (or department chair for off-campus projects), and completed an acceptable honors-level capstone written project based on the research.

## The Chemistry Minor

The Chemistry Minor is a six-course program designed to allow students with an interest in chemistry an opportunity to participate in the exciting Discovery Chemistry Core curriculum and to explore advanced work in one or more of the five foundation areas of chemistry: analytical, physical, inorganic, organic and biochemistry. All Chemistry minors begin their curriculum with the Discovery Chemistry Core, which includes Atoms and Molecules (CHEM 181), Organic Chemistry 1 (CHEM 221), Organic Chemistry 2 (CHEM 222), and Equilibrium and Reactivity (CHEM 231). Chemistry minors then choose and successfully complete two courses. One course must be Instrumental Chemistry and Analytical Methods, CHEM 300, which introduces experimental and instrumental methods essential to modern chemistry. This is considered a gateway course to the upper level of the curriculum. The final course to complete the minor may be any 300-level CHEM listed non-research course. Enrollment in the minor may be initiated as early as the second semester of the second year.

## Biochemistry Concentration

The Departments of Biology and Chemistry jointly offer a concentration that focuses on the study of the chemistry underlying biological structure and function. Concentrators must be enrolled as either biology or chemistry majors. Participants take Biology 120 or 131 and the Discovery Chemistry Core, which includes Chemistry 181, 221, 222 and 231. Students must also take Biology 301 or Chemistry 301, as well as Biology 302, 303 and 304, Chemistry 336, and one additional biology course with an associated biochemistry-oriented laboratory (only chemistry majors can count Biology 261 for this course). Students must also complete the usual requirements for their major. Concentrators also complete a two-semester thesis project in their fourth year involving research on some aspect of biochemistry. Admission to the concentration is competitive and occurs in the second semester of the second year. Students enrolled in the Biochemistry Concentration are not eligible for the Chemistry Minor.

## Other Programs Involving Chemistry

**Environmental Studies Concentration:** Students interested in concentrating in Environmental Studies are required to take a number of science courses. The Chemistry Department regularly offers environmentally related courses including Environmental Chemistry (CHEM 141), Equilibrium and Reactivity (CHEM 231), Instrumental Chemistry and Analytical Methods (CHEM 300). In addition, environmental capstone research projects are typically available in association with selected faculty members.

**Premedical Program:** Students in the premedical program must successfully complete the Discovery Chemistry Core (CHEM 181, 221, 222, 231), typically taken in the order listed and beginning in the first or second year.

**Teacher Education Program:** Students in the teacher education program will meet all chemistry requirements for certification as a secondary or middle school chemistry teacher in Massachusetts (MA Chemistry License), with successful completion of the Chemistry Major plus one course/project in the history and philosophy of science (e.g., PHIL 271). Students should select one course in biochemistry as one of their electives. Formal application to the Teacher Education Program (TEP) and additional education courses are also required for licensure. Since Massachusetts teacher certification requirements continue to evolve, students should work closely with the Chemistry Department TEP Liaison to make sure all state requirements are met.

**Advanced Placement Credit:** Knowledge and experience gained in high school AP courses provide an excellent background for our Discovery Chemistry Core. While AP credit in Chemistry cannot be counted towards the minimum number of courses required in the major or advanced standing in the chemistry curriculum, this credit can count towards the 32-course graduation requirement.

## Courses

### Chemistry 141 — Environmental Chemistry

*Every third year*

Investigates the chemistry of the Earth's environment through systematic studies of our atmosphere, hydrosphere and lithosphere and the exchange and interplay between them. The primary focus of the course will be environmental change taking place today including those that threaten plant and animal habitats and pose hazards to human health. Understanding of our environment and current threats to it will be gained through a combination of readings, lectures, discussions, demonstrations, and problem sets. One unit.

### Chemistry 144 — Chemistry and Society

*Annually*

Acquaints non-science majors with chemistry as a human endeavor and helps them acquire some appreciation of the benefits and limitations of science. Readings from the current popular and scientific literature are examined to illustrate the relationships of science to society. Some of the basic concepts and principles of chemistry necessary for an understanding of environmental problems will be considered in detail. One unit.

### Chemistry 181 — Atoms and Molecules

*Fall*

This introductory general chemistry course leads students to explore in-depth the scientific method through the formulation and testing of hypotheses in the laboratory. Laboratory experiments lead students to discover basic principles, i.e., stoichiometric relationships, electronic configuration and molecular structure. Lectures will explain and expand upon laboratory results. This course is suitable for students seeking to satisfy the science distribution requirements. It is also the first course in the sequence for science majors and premedical students. The lecture portion of this course meets four hours per week. One two-hour "discovery" laboratory session per week is included. One and one-half units.

### Chemistry 221 — Organic Chemistry 1

*Spring*

A study of organic compounds from the points of view of the chemistry of the functional groups, modern structural theory and reaction mechanisms. The chemistry of aliphatic hydrocarbons, alkenes, alkynes, dienes, alkyl halides, alcohols and ethers is introduced in a discovery mode. Substitution, addition and elimination mechanisms are studied in detail. Emphasis is placed on stereochemistry. The lecture portion meets four hours per week. One two-hour "discovery" laboratory session per week is included. Students learn various techniques of separation, purification, and spectroscopic analysis of organic compounds in the labora-

tory. There is an emphasis on one-step synthetic conversions which introduce the reactions to be studied in the lecture course. Prerequisite: Chemistry 181. (It is strongly recommended that students with a grade below C in Chemistry 181 do not continue with Chemistry 221 (see Chemistry 110)). One and one-half units.

### **Chemistry 222 — Organic Chemistry 2**

*Fall*

A continuation of Chemistry 221. Aromatic compounds, alcohols, ethers, aldehydes, ketones, amines, carboxylic acids and their derivatives are studied. Aromatic substitution, acyl transfer and carbonyl condensation reactions are developed. The mechanistic implications and synthetic applications of these organic reactions are evaluated. One four-hour “discovery” laboratory session per week is included. Microscale synthetic techniques and identification (chemical and spectroscopic) of organic compounds are included. Prerequisite: Chem 221. (A student should obtain a grade of C or better in Chemistry 221 to continue in Chemistry 222.) One and one-half units.

### **Chemistry 231 — Equilibrium & Reactivity**

*Spring*

Focuses on studying and understanding the role equilibrium, thermodynamics and kinetics play in chemical systems. Specific topics include phase and chemical equilibria, colligative properties of solutions, acid/base equilibria, chemical kinetics, electrochemistry, thermodynamics including enthalpy, entropy and free energy, and gas laws. Laboratory focused, this general chemistry course also introduces students to modern analytical instrumentation (such as UV-Vis spectrophotometer and GC-TCD) while developing critical wet chemical analytical techniques. Knowledge and skills gained in Chem 181, 221 and 222 will be built upon with an emphasis on obtaining quantitative understanding. One four-hour “discovery” laboratory session per week is included. Prerequisites: Chemistry 222 (or permission of Chair) and one semester of college calculus. One and one-half units.

### **Chemistry 300 — Instrumental Chemistry and Analytical Methods**

*Annually*

The application of instrumentation to chemical research and analysis has had a dramatic impact on the field of chemistry. As chemists, we must understand how instrumentation works in order to exploit its capabilities. This course focuses on spectroscopic, chromatographic and mass spectrometric methods of analysis. Specific analytical techniques included are molecular and atomic UV-Vis spectroscopy, infrared spectroscopy, electrochemistry, TLC, GC, HPLC, and mass spectrometry (GC-MS). Laboratory and lecture work emphasize understanding instrumental design, major analytical methods of analysis and method development. When the student finishes this course he or she should be able to understand how and/or why instruments are designed to operate according to certain specific criteria and make intelligent choices among several possible ways of solving an analytical problem. Furthermore, the student should have confidence in his/her ability to work with modern chemical instrumentation. One four-hour laboratory session per week is included. Prerequisite: Chemistry 231, prerequisite or corequisite: Physics 111 (with laboratory) or Physics 115. One and one-half units.

### **Chemistry 301 — Biochemistry**

*Annually*

A detailed study of the chemistry of biological molecules, with a focus on the structure of biological macromolecules and the chemical mechanism of biochemical transformations. Topics may include the structure and synthesis of proteins, nucleic acids, carbohydrates and lipids, enzymatic catalysis, biological thermodynamics, glycolysis and gluconeogenesis, the citric acid cycle, fatty acid oxidation, oxidative phosphorylation, and metabolic regulation. A strong background in thermodynamics and organic chemistry is highly recommended. This course may serve as a prerequisite for Biology 302. Students may not count both Biology 301 and Chemistry 301 for credit. Prerequisites: Chemistry 222 and 231. One unit.

### **Chemistry 304 — Synthetic Organic Chemistry**

*Every third year*

Covers a selection of modern synthetic methods and reagents used in organic chemistry. Topics to be presented include oxidation/reduction, organometallic reactions, functional group interconversions, protecting group strategies, enolate additions, and pericyclic reactions with a focus on asymmetric synthesis. The course will build upon the individual methods discussed to ultimately demonstrate their combined use in the synthesis of complex organic molecules. Prerequisite: Chemistry 222. One unit.

### **Chemistry 309 — Spectroscopy**

*Every third year*

This course focuses on chemical structure identification through the interpretation of spectroscopic data. With a concentration on organic molecules, Mass, Vibrational (IR and Raman), and Magnetic Resonance (NMR and EPR) spectra are analyzed. There is an emphasis on NMR spectroscopy (including an introduction to modern multipulse techniques) to elucidate molecular structure. The course is conducted with a problem-solving approach and student participation is expected. Prerequisite: Chemistry 222. One unit.

**Chemistry 317 — Nanotechnology***Every third year*

Introduces students to nanometer scale material and devices. Materials in this size regime often possess unusual properties that have application in molecular electronics, medical diagnostics and devices, molecular motors, and self-assembly and surface chemistry. Students will read a variety of books and scientific articles from peer reviewed journals. Nanotechnology is a multidisciplinary field of study where projects often require collaborations between chemists, physicists, biologists and engineers. Students other than chemistry majors who have completed the prerequisites are encouraged to enroll to broaden both their own perspective and that of the class. Prerequisites: Chemistry 222 and 231. One unit.

**Chemistry 335 — Quantum Mechanics and Spectroscopy***Annually*

The course is a study of the basic concepts, principles and methods of modern physical chemistry. Physical chemistry asks “how?” and/or “why?” things happen as they do. Here, the emphasis will be on developing a deeper understanding of the microscopic properties that govern chemical phenomena. The topics covered may include quantum mechanics, statistical mechanics, spectroscopy, group theory, and kinetics and computational chemistry. One four-hour laboratory session per week is included. In the lab you will learn techniques and analyses related to physical chemistry and will develop your scientific writing skills. Prerequisites: Chemistry 231 and Mathematics 134 or Mathematics 136 and Physics 111, (with laboratory) or Physics 115. One and one half units.

**Chemistry 336 — Chemical Thermodynamics***Annually*

This course is a study of the basic concepts, principles and methods of classical physical chemistry. Physical chemistry asks “how?” and/or “why?” things happen as they do. Here, the emphasis will be on developing a deeper understanding of the macroscopic properties that govern chemical phenomena. The topics covered may include thermodynamics, chemical and phase equilibria, kinetics, reaction dynamics, statistical mechanics, and complex solution behavior. Prerequisites: Chemistry 231 and Mathematics 134 or 136 and Physics 111 (with laboratory) or Physics 115, 116. One unit.

**Chemistry 351 — Inorganic Chemistry***Spring*

Group theory and modern theories of bonding are used to discuss structural and dynamic features of inorganic compounds. The structure and bonding of transition metal coordination compounds are related to various reaction mechanisms. The principal structural and mechanistic features of transition metal organometallic chemistry are studied with emphasis on catalysis of organic reactions. The role of inorganic chemistry in biological systems is also explored. Prerequisite or Co-requisite: Chemistry 335. One unit.

**Chemistry 352 — Inorganic Chemistry Lab***Annually*

This advanced laboratory course is designed to introduce students to the synthetic and characterization methods of modern inorganic chemistry. Students synthesize and purify compounds by a variety of techniques. Compounds are characterized using modern instrumentation. The course emphasizes synthetic techniques and analysis of compounds using various spectroscopic techniques; learning is reinforced by report writing. Prerequisite or co-requisite: Chemistry 351. One-quarter unit.

**Chemistry 361 — Biophysical Chemistry***Every third year*

This course aims to develop an understanding of the chemical interactions that govern the structure and function of biological molecules. A thorough discussion of the spectroscopic techniques used in modern research for analyzing such molecules will be incorporated. In addition, the course covers topics in protein folding and mis-folding (as associated with disease), focusing in particular on the thermodynamic and kinetic processes involved. Time will be spent reading and discussing primary literature with an emphasis on interpreting the results obtained by others. One unit.

**Chemistry 381 — Bioinorganic Chemistry***Every third year*

This course is organized around the important biological proteins, enzymes and other biological systems that utilize metal ions. An important goal is to explain their functional/positional importance based on the chemistry at the metal center(s). Topics include bioinorganic systems such as photosynthesis, hemoglobin/myoglobin and other iron proteins, copper proteins, and the biochemistry of zinc. Current research efforts in the field are discussed to demonstrate the dynamic nature of the subject. Prerequisite: Chemistry 351. One unit.

**Chemistry 389 — Introduction to Research***Fall, spring*

Involves a commitment to join a research group. Specific activities will be established with the individual Research Advisor but may include: attendance of group meetings, working on a lab or computer project with other group members, and/or reading/discussing literature related to group research. The course is by

permission only. It is taken as an overload and receives no grade. It may be taken more than once. Interested students are invited to apply early in the fall or spring of the second, third or fourth year. The candidate's academic record will be reviewed to determine if the student could reasonably benefit from such a program. Prerequisites/Corequisites: Chemistry 222 or 231. No units.

### **Chemistry 390 — Independent Research**

*Fall, spring*

Involves an original and individual experimental investigation with associated literature study in one of the fields of chemistry under the supervision of a member of the faculty. The culmination of all research projects will be a report. The course is by permission only. Interested students are invited to apply before the registration period in the spring of the second or third year or the fall of the third or fourth year. The candidate's academic record will be reviewed to determine if the student could reasonably benefit from such a program. This course does not count toward the minimum number of chemistry courses required of the major. Prerequisites: Chemistry 222 and 231 or prior research experience at Holy Cross. One unit.

### **Chemistry 399 — Special Topics**

*Annually*

Courses explore various topics in chemistry. The subject and format varies with each offering. One unit.

### **Chemistry 405, 406 — General Research 1 and 2**

*Fall, spring*

Involves an original and individual experimental and/or computational investigation with associated literature study in one of the fields of chemistry under the supervision of a member of the faculty. The culmination of all research projects will be a report, as well as an oral presentation to be given during the spring semester. Students will be required to attend the weekly department seminar program (fall and spring). Chemistry 405 is the first course of the consecutive two-semester research experience and carries no course credit; it is taken as an overload, on an "in-progress" basis. A grade will be given upon completion of Chemistry 406, which carries one and one-half units. Satisfactory completion of Chemistry 405 (including a poster presentation) is a prerequisite for Chemistry 406. Each course is by permission only. Interested students are invited to apply before the registration period in the spring of the second or third year. Application in the first year requires nomination by a faculty member. Taking Chemistry 405 in the spring semester requires approval of the Department Chair. The candidate's academic record will be reviewed to determine if the student could reasonably benefit from such a program. Prerequisites: Chemistry 222 and 231 or prior research experience at Holy Cross. One and one-half units.

### **Chemistry 407, 408 — General Research 3 and 4**

*Fall, spring*

This program builds on the experiences gained in Chemistry 405 and 406. The second year of research provides the opportunity for further in-depth investigations. The culmination of all research projects will be a report and oral presentation to the chemistry faculty during the spring semester. Students will be required to attend the weekly departmental seminars program (fall and spring). Chemistry 407 is the first course of this consecutive two-semester research experience and carries no course credit; it is taken as an overload, on an "in-progress" basis. A grade will be given upon completion of Chemistry 408, which carries one and one-half units. Chemistry 408 can not be counted toward the required minimum number of chemistry courses. Satisfactory completion of Chemistry 407 (including a poster presentation) is a prerequisite for Chemistry 408. Both Chemistry 407 and 408 are by permission only. Interested students normally apply before the registration period in the spring of the third year. The candidate's academic record to date, with particular attention given to performance in Chemistry 405 and 406, will be reviewed to determine if the student could reasonably benefit from such a program. Prerequisites: Chemistry 405 and 406. One and one-half units.

### **Chemistry 410 — Advanced Research**

This program builds on the experiences gained in prior research courses, providing the opportunity for further in-depth investigations. The culmination of all research projects will be a written report and a presentation to the chemistry faculty. Students will be required to attend the weekly departmental seminars program. This course is by permission only. Interested students normally apply to the department before the relevant registration period. The candidate's academic record to date, with particular attention given to performance in prior research courses, will be reviewed to determine if the student could reasonably benefit from such a program. Prerequisites: Chemistry 390, 405/406 or 407/408. One and one-quarter units.