

CHEMISTRY

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The wide range of courses offered by the Department of Chemistry reflects the position of chemistry as the foundation of all the molecular sciences. In addition to graduate work in chemistry, biochemistry, or health-related disciplines, the department's graduates find their broad scientific training useful in fields such as technology policy, business management, and law. Chemistry is an especially appropriate major for students interested in energy research or policy and the environment.

COURSES FOR NONMAJORS WITHOUT PREREQUISITES

The Chemistry department offers one-term courses with no prerequisites, which are intended for non-science majors. These courses do not satisfy medical school requirements or the general chemistry requirement for any science major. Courses for nonmajors are numbered CHEM 100–109.

PREREQUISITES AND INTRODUCTORY COURSES

Prerequisite courses Required prerequisites for the Chemistry degree programs are: two terms of general chemistry and laboratory; single-variable calculus at the level of MATH 115 or MATH 116; and one term of introductory physics numbered 170 or higher, or advanced placement beyond these levels in math or physics. Students also are encouraged to complete a course in multivariable calculus (MATH 120, MATH 121, or ENAS 151); these courses or more advanced math courses fulfill the math prerequisite. All prerequisite courses must be taken for a letter grade; if they are taken as Audit or Credit/D/Fail they will not satisfy the requirement.

Introductory courses The majority of students begin with a general chemistry sequence: either CHEM 161 and 165 or CHEM 163 and 167. These courses fulfill the prerequisite for general chemistry in the Chemistry major. Students taking CHEM 161 may be studying chemistry for the first time, perhaps took chemistry as a high school sophomore, or even may have completed AP chemistry but did not fully master the subject at that level. Students in CHEM 163 will have completed a year or two of chemistry later in high school, although motivated students may have last taken chemistry as a high-school sophomore if they have a strong math and physics background. Typically students who complete CHEM 163 in the fall term complete CHEM 167 in the spring term. Regardless of whether a student completes the CHEM 161 and 165 sequence or the CHEM 163 and 167 sequence, the introductory laboratory sequence is CHEM 134L and 136L; each laboratory course gives one-half course credit.

Students with a sufficiently strong background in chemistry may initiate their studies with courses in organic or physical chemistry after demonstrating proficiency on the department's placement examination. While CHEM 174 and 175 are offered only to first-year students, other courses in organic chemistry, including CHEM 220 and 221, also are available to qualified first-year students. Students with a strong background in physics and calculus may be eligible for the physical chemistry

courses CHEM 332 and 333 in the first year if they have fulfilled the math and physics requirements.

PLACEMENT PROCEDURES

Details about placement and preregistration for chemistry courses can be found on the department website. Information about the placement examination and advising also are available on the department website.

Permission Enrollment in CHEM 163 or CHEM 174 through the registration system requires permission from the department. Permission is issued automatically after placement has been completed for entering first-year students. For more information email chemistry.dus@yale.edu.

Upper-level students Upper-level students wishing to take CHEM 161 or 163 should confirm their placement on Canvas@Yale by accessing the Chemistry Placement site that corresponds to their year of matriculation. If permission is required in the registration system, upper-level students should write to chemistry.dus@yale.edu. Those wishing to enroll in CHEM 220 may do so as long as they have satisfied the general chemistry prerequisite.

Section registration in laboratory and lecture courses Information about online registration for laboratory and discussion sections can be found in the description for each laboratory or lecture course in Yale Course Search.

Advanced courses All chemistry advanced lecture courses numbered 400 and higher are half-semester courses, which count for 0.5 Yale College credits. These courses are held in the first half of the semester or in the second half of the semester. Information about the timing of courses is available in Yale Course Search. Because most advanced courses are offered either in the fall term or have a fall-term course as a prerequisite, students should give consideration to the advanced courses they plan to take in the spring term. For the purpose of degree requirements, all undergraduate Chemistry courses numbered 401 or higher, approved by the director of undergraduate studies (DUS), typically count as advanced lecture or laboratory courses, as do CHEM 226L, 251L, 331L, 349L, 355L, and 335L. Many graduate-level Chemistry courses (those numbered 500 and above) also may count toward the advanced-course requirement; consult the DUS for information about eligible courses.

For premedical students Medical schools currently require one year of organic chemistry and laboratory as well as one year of general chemistry and laboratory. The general chemistry requirement may be satisfied by completing CHEM 161 and 165, CHEM 163 and 167, or two terms of physical chemistry. Students should consult with the Office of Career Strategy for the most up-to-date premedical course advice.

REQUIREMENTS OF THE MAJOR

Four degree programs are offered: the B.A., the B.S., an intensive major leading to the B.S., and the combined B.S./M.S. The B.A. degree is intended for students who want solid training in the chemical sciences and who also intend to study other subjects in which chemical training would be an asset, such as technology policy, economics, or the environment. The B.S. degree is intended to prepare students for graduate study while permitting extensive exploration of other disciplines and is also recommended for those planning to attend graduate school. The B.S. degree with an intensive major provides

more focused preparation for a career in chemical research, and requires greater breadth in laboratory courses and electives. The combined B.S./M.S. is designed for students whose advanced preparation qualifies them for graduate-level work in their third and fourth years of college.

The major requires a group of prerequisites or their equivalent in advanced placement, a core of courses common to all four degree programs, advanced courses specific to each degree program, and a senior requirement.

Course requirements common to all Chemistry degree programs All degrees require the following 5 credits with two terms of organic chemistry (CHEM 174 or 220, and CHEM 175, 221, or 230) with laboratory (CHEM 222L and 223L), one term of physical chemistry (CHEM 332 or 328), and one term of inorganic chemistry (CHEM 252).

B.A. degree program The B.A. degree program requires ten course credits beyond the prerequisites. In addition to the common degree requirements and one-term senior requirement, the B.A. degree requires four additional course credits of advanced chemistry lecture or laboratory courses. At least one full credit must be attained through advanced lecture courses in the Chemistry department and at least one must be a Chemistry laboratory course. CHEM 333 may be counted toward the advanced-course requirement, although not as the sole lecture course.

B.S. degree program The B.S. degree program requires thirteen course credits beyond the prerequisites. In addition to the common degree requirements and two-term senior requirement, the B.S. degree requires completion of a second term of physical chemistry (CHEM 333), one term of physical chemistry laboratory (CHEM 330L), and four additional course credits of advanced chemistry lecture or laboratory courses. At least one full credit must be attained through advanced lecture courses in the Chemistry department and at least one must be a Chemistry laboratory course.

B.S. degree program, intensive major The B.S. degree program, intensive major requires fifteen course credits beyond the prerequisites. In addition to the common degree requirements and two-term senior requirement, the B.S. degree with an intensive major requires completion of a second term of introductory physics numbered 171 or higher, a second term of physical chemistry (CHEM 333), one term of physical chemistry laboratory (CHEM 330L), and five additional course credits of advanced chemistry lecture or laboratory courses. At least two full credits must be attained through advanced lecture courses in the Chemistry department and at least one must be a Chemistry laboratory course.

Combined B.S./M.S. degree Exceptionally well-prepared students may complete a course of study leading to the simultaneous award of the B.S. and M.S. degrees after eight terms of enrollment. Formal application for admission to this program must be made no later than the last day of classes in the fifth term of enrollment. To be considered for admission, by the end of their fifth term applicants must have achieved at least two-thirds A or A- grades in all of their course credits as well as in all of the course credits directly relating to the major, including prerequisites. Two terms of CHEM 490 must be taken in the fifth and sixth terms with earned grades of A or A- to continue in the program. The B.S./M.S. degree program requires completion of the intensive major requirements, including the senior requirement, which typically is completed in the fifth and sixth terms. The introductory physics requirement must

be fulfilled with PHYS 200 and 201 or PHYS 260 and 261; a term course in physics numbered 400 or higher and approved by the Chemistry DUS may be substituted for the introductory sequence. In addition, eight credits of graduate courses in chemistry (four of which count toward the B.S.) are required. Four terms of research are required, including two terms of research taken in CHEM 990. Students in the program must earn grades of A in at least two of their graduate-level term courses (or in one yearlong course) and have at least a B average in other graduate-level courses. B.S./M.S. candidates also are expected to continue their independent research in a summer internship between their junior and senior years. At the end of their eighth semester students are required to write a thesis summarizing their research activities. The thesis must be written under the guidance of the faculty member who supervises the student's research and it must be submitted to their research adviser on the final day of classes of the student's eighth semester. The thesis should be no shorter than twenty-five pages (double-spaced, twelve-point font, excluding figures, tables, and bibliography) and normally should contain the following sections: Introduction, Results and Discussion, Summary and Conclusions, Research Methods, and Bibliography. Students in the B.S./M.S. program, must also present their research in the form of a poster presentation at the end of their sixth semester (to fulfill the requirements of the B.S. degree) and an oral presentation at the end of their eighth semester (to fulfill the requirements of the M.S. degree). Both the poster and oral presentation are coordinated by the instructor of CHEM 490. For more information, see Academic Regulations, section L, Special Academic Arrangements, "Simultaneous Award of the Bachelor's and Master's Degrees."

Credit/D/Fail No chemistry courses taken Credit/D/Fail may be counted toward the major (including substitutions for advanced courses).

SENIOR REQUIREMENT

For the B.A. degree program Students in the B.A. degree program must complete the senior seminar CHEM 400, in which they prepare a capstone essay on a chemistry-related topic. The capstone essay is expected to be 15–25 pages in length (double-spaced, twelve-point font, exclusive of figures, tables, and bibliography).

For the B.S. degree program Students in the B.S. degree program may fulfill the senior requirement by completing two terms of the independent research course CHEM 490 and writing a capstone report under the guidance of a faculty member that describes their research activities. Alternatively, they may complete the senior seminar CHEM 400, in which they prepare a capstone essay on a chemistry-related topic, and complete one additional course credit of advanced chemistry lecture or laboratory course or CHEM 490. The capstone report or essay is expected to be 15–25 pages in length (double-spaced, twelve-point font, exclusive of figures, tables, and bibliography). All students performing research also must present their work in the form of an oral or poster presentation as coordinated by the instructor of CHEM 490.

For the B.S. degree program with an intensive major Students in the B.S. degree program with an intensive major fulfill the senior requirement by completing two terms of the independent research course CHEM 490 and writing a capstone report of 15–25 pages in length (double-spaced, twelve-point font, exclusive of figures, tables, and bibliography) under the guidance of a faculty member that describes their research

activities. Students in the intensive major program also must present their work in the form of an oral or poster presentation as coordinated by the instructor of CHEM 490.

ADVISING

Majors are encouraged to begin their programs in the first year to provide the greatest flexibility in scheduling. It is possible, however, to complete the B.S. in as few as six terms if a student has advanced placement. One sample B.S. program follows, but many others are possible:

First-Year	Sophomore	Junior	Senior
CHEM 161, 165, 134L, 136L, math prereq	CHEM 220, 221, 252, 222L, 223L, physics prereq	CHEM 332, 333, 330L, 251L, 1 elective (1 credit)	2 terms of CHEM 490, 2 electives (2 credits)

Substitutions for required courses Up to two credits of advanced science courses outside Chemistry may be counted as electives, with the written approval of the DUS. CHEM 490 may not in any circumstance be substituted for any of the laboratory requirements. The graduate courses CHEM 562L, 564L, and 565L may not be counted toward any requirement of the major.

Programs of study with special emphasis The flexibility of the degree requirements makes it possible for a student's program of study to emphasize a particular area of specialization in chemistry. For example, a program specializing in chemical biology may include CHEM 419 and biochemistry electives such as MB&B 300 or 301. An inorganic chemistry specialization could include CHEM 402 and 403. A program with emphasis in physical chemistry and chemical physics would have electives such as CHEM 466, 472, or 496. Students interested in synthetic organic chemistry could complete electives such as CHEM 416, 423, or 528. An emphasis in biophysical chemistry includes a course in either chemical biology or biochemistry, as well as electives chosen from graduate courses in biophysics or biochemistry. Students may design programs with other areas of emphasis in consultation with the DUS. For a list of graduate courses appropriate for a particular specialization, consult the DUS.

Approval of major programs of study All Chemistry majors in their sophomore, junior, and senior years must have their programs approved by the DUS. A program tailored to each student's goals is created and recorded on a Chemistry Course of Study (COS) form and submitted to chemistry.dus@yale.edu.

STUDY ABROAD

Chemistry majors wishing to study abroad typically find their course of study easier to schedule if the semester abroad is a spring term. Students studying abroad in the spring term of their junior year are required to obtain approval for the project that will fulfill their senior requirement before the end of the prior term. For general information on the Year or Term Abroad, see Academic Regulations, section K, Special Academic Programs, "Year or Term Abroad."

UNIQUE TO THE MAJOR

Special restrictions on lecture courses For the general, organic, or physical chemistry sequences, CHEM 161 and 165; CHEM 174 or 220 and CHEM 175, 221, or 230; and CHEM 332 or CHEM 328 and 333, completion of the first term with a passing grade is a

prerequisite for registration in the subsequent term. Completion of CHEM 163 with a passing grade is a prerequisite for registration in CHEM 167.

Students receive credit for only one chemistry sequence of any given type. For example, a student who has completed CHEM 161 and 165 may not subsequently enroll in CHEM 163 or 167; a student who has completed CHEM 174 and 175 may not subsequently enroll in CHEM 220, 221, or 230. Similarly, students may not enroll in a course (typically of lower number) that is a prerequisite to a course they already have taken. For example, a student who has completed an organic chemistry laboratory cannot subsequently enroll in a general chemistry laboratory.

Special restrictions on laboratory courses Although the department does not recommend it, chemistry courses may be taken without the accompanying laboratory. However, the appropriate lecture course is a prerequisite or corequisite for each laboratory course. Students dropping the lecture course corequisite with a laboratory must also drop the laboratory course.

SUMMARY OF MAJOR REQUIREMENTS

Prerequisites CHEM 161 and 165 or CHEM 163 and 167; CHEM 134L and 136L; MATH 115 or 116; (MATH 120, MATH 121, or ENAS 151 suggested); PHYS 170, 180, 200, or 260; or equivalents in adv placement

Number of courses *B.A.* – 10 course credits, beyond prereqs (incl senior req); *B.S.* – 13 course credits, beyond prereqs (incl senior req); *B.S., intensive major* – 15 course credits, beyond prereqs (incl senior req)

Specific courses required *All degrees* – 2 terms of organic chem (CHEM 174 or 220 and CHEM 175, 221, or 230); 2 terms of organic chem lab (CHEM 222L and 223L); 1 term of physical chem (CHEM 332 or 328); 1 term of inorganic chem (CHEM 252); *B.S.* – CHEM 330L, 333; *B.S., intensive major* – CHEM 330L, 333; second term of intro physics, PHYS 171 or higher

Distribution of courses *B.A. and B.S.* – 4 addtl course credits in adv lectures or labs, incl at least 1 lecture credit and 1 lab; *B.S., intensive major* – 5 addtl course credits in adv lectures or labs, incl at least 2 credits of lectures and 1 lab

Substitution permitted Up to 2 relevant adv science courses in other departments for adv chemistry courses with DUS permission

Senior requirement *B.A.* – CHEM 400; *B.S.* – 2 terms of CHEM 490, or CHEM 400 and 1 addtl course credit in adv lecture or lab; *B.S., intensive major* – 2 terms of CHEM 490; all degree programs require submission of senior capstone essay

Prerequisites and Introductory Courses

- 2 terms of general chemistry (CHEM 161, 165 or CHEM 163, 167) and accompanying laboratories (CHEM 134L, 136L); students with strong chemistry background may place into higher-level Chemistry options
- 1 term of physics, number 170 or higher (or equivalents in advanced placement)

- MATH 115 or MATH 116 (these upper-level courses also fulfill math requirement: MATH 120, MATH 121, ENAS 151)

Common Degree Requirements

6 courses (5 credits)

- 2 terms of organic chemistry, CHEM 174 or CHEM 220 and CHEM 175, CHEM 221, or CHEM 230
- 2 terms of organic chemistry laboratory, CHEM 222L and CHEM 223L (each .5 credit)
- 1 term of physical chemistry, CHEM 332 or CHEM 328
- 1 term of inorganic chemistry, CHEM 252

B.A. Degree

10 course credits beyond the prerequisites

- Common degree requirements listed above
- 4 course credits of advanced Chemistry lecture, one of which must be a CHEM lab and one must be a full-credit lecture
- CHEM 400

B.S. Degree

13 course credits beyond the prerequisites

- Common degree requirements listed above
- CHEM 333
- CHEM 330L
- 4 course credits of advanced Chemistry lecture, one of which must be a CHEM lab and one must be a full-credit lecture
- Two terms of CHEM 490 to include a capstone report or CHEM 400 to include a capstone report with one additional advanced chemistry lecture or laboratory course

B.S. Degree, Intensive

15 course credits beyond the prerequisites

- Same requirements as the B.S. Degree, except 5 course credits of advanced Chemistry lecture or lab, one of which must be a CHEM lab and one must be a full-credit lecture
- 1 term of physics, in a course numbered 171 or higher (in addition to the physics prerequisites)
- 2 terms of CHEM 490 to include a capstone report and oral or poster presentation

B.S./M.S. Degree

See Overview page and Chemistry website.

The wide range of courses offered by the Chemistry department reflects chemistry's position as the foundation of all the molecular sciences. Chemistry majors learn about the molecular basis of natural phenomena and use this knowledge in chemical research. The department's graduates are well prepared to conduct advanced studies in chemistry, biochemistry, and medicine, and they find their broad scientific training useful in diverse fields including business, management, and law. As the problems of society encompass ever more complex scientific issues, a chemistry degree is an increasingly appropriate choice for students whose careers will involve energy policy, the environment, government, or public service.

Chemistry is a core science important to many academic programs. Premedical students are advised to take two semesters of chemistry including laboratory in their first year. Many science and engineering majors require a full year or more of chemistry with associated laboratories. The cumulative nature of science education makes it important for individuals contemplating such majors to complete one of the introductory chemistry sequences as first-year students.

Because entering students have a diverse range of prior exposure to science, the Yale curriculum provides several different ways to begin the study of chemistry. Most first-year students enroll in a general chemistry course, while individuals with an especially strong science background may elect to take a placement examination (administered by the department online in July) and accelerate into more advanced courses.

INTRODUCTORY COURSES

Students may begin the study of university-level chemistry with one of the following:

- CHEM 161 and CHEM 165, a two-term general chemistry sequence appropriate for students with no previous background in chemistry or with one year of high-school level chemistry
- CHEM 163 and CHEM 167, a two-term general chemistry sequence appropriate for students with stronger problem-solving skills and/or a solid high-school chemistry preparation. Typically students who start in CHEM 163 in the Fall semester, will continue with CHEM 167 in the Spring Semester.

Regardless of the starting point, all paths fulfill medical school requirements and chemistry requirements for several other majors, and each path prepares students for subsequent study of organic chemistry.

ADVANCED COURSES FOR FIRST-YEAR STUDENTS

Students with very strong backgrounds in chemistry and problem solving can affirm their mastery of general chemistry by taking the departmental placement examination. Sufficiently well-prepared students are permitted to take an organic chemistry course limited to first-year students, the sophomore-level organic chemistry course, or junior-level physical chemistry. Completing an advanced course accelerates completion of the requirements for many majors and pre-professional programs. For details see the department website.

PREMEDICAL REQUIREMENTS

Medical schools typically require a year of general chemistry, a year of organic chemistry, and often a term of biochemistry. Students taking either physical chemistry or organic chemistry as first-year students receive two acceleration credits that document their placement, and these are usually accepted by medical schools for the general chemistry requirement. Students choosing physical chemistry as first-year students continue by completing organic chemistry as sophomores. First-year students completing organic chemistry most often fulfill their remaining medical school chemistry requirements by completing a course in biochemistry or another advanced chemistry course. All students are advised to consult with a premedical adviser early in their studies, as the chemistry requirements for different medical schools can vary significantly.

LABORATORIES

Most introductory lecture courses are accompanied by laboratories, and students normally take the lecture and the laboratory courses together. The laboratory, when not required by the instructor, can be postponed or not taken, but this is strongly discouraged. Information about registration for sections is provided for each laboratory course in Yale Course Search.

PLACEMENT

Details about placement and preregistration for chemistry courses can be found on the department website. Information about the placement examination and advising sessions also are available on the department website.

CHEMISTRY PREPARATION FOR DIFFERENT MAJORS

Majors in Chemistry, Chemical Engineering, and Molecular Biophysics and Biochemistry require physical chemistry. Students who can begin their chemistry study with organic or physical chemistry usually complete such majors faster. Beginning Chemistry majors who wish to complete medical school admissions requirements should plan to complete two terms of chemistry with laboratory and one term of calculus or higher-level mathematics during their first year.

FACULTY OF THE DEPARTMENT OF CHEMISTRY

Professors Victor Batista, Gary Brudvig, Robert Crabtree (*Emeritus*), Jason Crawford, †Craig Crews, R. James Cross, Jr. (*Emeritus*), Jonathan Ellman, John Faller (*Emeritus*), Sharon Hammes-Schiffer, Nilay Hazari, Seth Herzon, Patrick Holland, Mark Johnson, William Jorgensen, J. Patrick Loria, James Mayer, J. Michael McBride (*Emeritus*), Scott Miller, Peter Moore (*Emeritus*), Timothy Newhouse, †Anna Pyle, †James Rothman, Martin Saunders (*Emeritus*), †Dieter Söll, David Spiegel, †Scott Strobel, John Tully (*Emeritus*), Patrick Vaccaro, Hailiang Wang, Kenneth Wiberg (*Emeritus*), Elsa Yan, Frederick Ziegler (*Emeritus*), Kurt Zilm

Associate Professor Sarah Slavoff

Assistant Professors Amarynne Bartholomew, Caitlin Davis, †Stavroula Hatzios, Stacy Malaker, †Mingjiang Zhong

Lecturers Paul Anastas, Paul Cooper, Christine DiMeglio, Jonathan Parr

Preceptors TBD

†A joint appointment with primary affiliation in another department.

See visual roadmap of the requirements.

For Nonmajors without Prerequisites Introductory Courses Intermediate Courses
Advanced Courses Graduate Courses of Interest to Undergraduates