CHEMISTRY

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FACULTY OF THE DEPARTMENT OF CHEMISTRY

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Associate Professor  Nilay Hazari

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† A joint appointment with primary affiliation in another department.

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.

Introductory courses and placement  The majority of students begin with a general chemistry sequence: either CHEM 161 and 165, General Chemistry I and II, or CHEM 163 and 167, Comprehensive University Chemistry I and II. Any of these courses fulfills the prerequisite for general chemistry in the Chemistry major. Students taking CHEM 161 may be taking chemistry for the first time, perhaps took chemistry as a high school sophomore, or may even have taken AP chemistry but not fully mastered the subject at that level. Students in CHEM 163 will have more recently completed a year or two of chemistry 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. Students who have done well in an advanced placement chemistry course or shown other evidence of high achievement in science and mathematics may be given placement to start in CHEM 167. For instance, students with a Chemistry Advanced Placement test score of 5 may usually elect CHEM 167.

Students with a sufficiently strong background in chemistry may initiate their studies with courses in organic, inorganic, or physical chemistry after demonstrating proficiency on the department’s placement examination. CHEM 174 and 175, Freshman Organic Chemistry I and II, and CHEM 185, Freshman Inorganic Chemistry, are offered expressly for freshmen. Other courses in organic chemistry, including CHEM 220, 221, and 230, are also available to qualified freshmen. Students with a strong background in physics and calculus may be eligible for the physical chemistry courses CHEM 332 and 333.

Placement procedures  The Chemistry department reviews the preparation of all freshmen prior to the beginning of the fall term, using test scores, admission records, and information supplied by students. Incoming students should see the Freshman Web site (http://yalecollege.yale.edu/new-students/class-2019/academic-information/special-programs-placement-and-preregistration-1) for details on information to submit during the summer before matriculation. The department determines the appropriate general chemistry course for every entering freshman, either CHEM 161, 163, or 167. Students will be able to view their initial placement in late August on the “Chem Placement 2015” site on Classes*v2 (https://classesv2.yale.edu/portal); instructions are available on the Freshman Web site (http://yalecollege.yale.edu/new-students/class-2019/academic-information/special-programs-placement-and-preregistration-0).

Freshmen wishing to take CHEM 174, 185, 220, or 332, or those wishing to take a higher-level course than their initially assigned placement, are required to take a placement examination on the first day of registration week in the fall term. Students who feel they have been placed incorrectly at too high a level may discuss changing their placement with a chemistry placement adviser and do not need to take the examination. Students uncertain about their placement are encouraged to sit for the examination, as it provides the best measure of a student’s readiness to enter the wide variety of courses offered to freshmen.

Students with placement questions, or those wishing to change their course preference indicated during preregistration, should attend the department’s orientation meeting prior to the placement examination. Additional sessions with placement advisers are scheduled throughout the first week of the fall term in 183 SCL at times listed in the Calendar for the Opening Days of College. Students wishing to change their placement should consult an adviser as soon as possible.
Students are advised to review general chemistry before taking the placement examination. They must bring a nonprogrammable, nongraphing calculator and a #2 pencil with them to the examination; cell phones may not be used. Times and places for the examination are published in the *Calendar for the Opening Days of College*. After the examination, final placements are posted on the “Chem Placement 2015” site on Classes*v2 (https://classesv2.yale.edu/portal). For further information about placement and the examination, consult the *Calendar for the Opening Days of College* and the Freshman Web site (http://yalecollege.yale.edu/new-students/class-2019/academic-information/special-programs-placement-and-preregistration-1).

**Permission keys** Enrollment in any introductory chemistry course requires an electronic permission key. Keys are issued automatically by the department for entering freshmen and are displayed as green key-shaped icons next to the appropriate courses on the online registration page. Students are blocked from enrolling in any chemistry course for which they do not possess a permission key. Students experiencing problems with permission keys should inquire in person at the department office, 183 SCL.

**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 Online Course Information (http://www.yale.edu/oci). Due to the nature of laboratory exercises, it is impractical to preview laboratory courses during the course selection period.

**Placement information for upperclassmen** Upperclassmen wishing to take CHEM 161, 163, 165, or 167 should confirm their placement at the Chem Placement site on Classes*v2 (https://classesv2.yale.edu/portal) that corresponds to their year of matriculation. If permission keys are needed, upperclassmen should obtain them by inquiring at the department office, 183 SCL. Those wishing to enroll in CHEM 220 may do so as long as they have satisfied the general chemistry prerequisite.

**Information 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, or CHEM 163 and 167, or CHEM 167 and 185, or two terms of physical chemistry. In most instances students with advanced placement taking only CHEM 167 may complete this requirement by taking a course in biochemistry, inorganic chemistry, or physical chemistry. Students should consult with the Office of Career Strategy (http://ocs.yale.edu/content/health-professions-0) for the most up-to-date premedical course advice.

**Major degree programs** Four degree programs are offered: a B.A., a B.S., an intensive major leading to a B.S., and a 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, the environment, or medicine. The B.S. degree is intended to prepare students for graduate study while permitting extensive exploration of other disciplines. 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. Students electing this major program can also satisfy the requirements for a certified degree in chemistry as set forth by the American Chemical Society. 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 for the Class of 2016 Students in the Class of 2016 may fulfill the requirements of the major that were in place when they entered the major in Chemistry, as described in previous editions of this bulletin (http://www.yale.edu(printer/bulletin/archivepdffiles/YCPS). Alternatively, they may fulfill the requirements for the major as described below for the Class of 2017 and subsequent classes.

**The major for the Class of 2017 and subsequent classes** 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. No chemistry courses taken Credit/D/Fail may be counted toward the major (including substitutions for advanced courses).

**Prerequisites common to all Chemistry degree programs** Two terms of general chemistry and laboratory, single-variable calculus at the level of MATH 115, and one term of introductory physics numbered 170 or higher, or the equivalents in advanced placement, are prerequisite to all four degree programs. Students are also encouraged to complete a course in multivariable calculus (MATH 120 or ENAS 151).

**Course requirements common to all Chemistry degree programs** All degrees require 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 185 or 252).

**B.A. degree** In addition to the prerequisites and common degree requirements, the B.A. degree requires four additional course credits of advanced chemistry lecture or laboratory courses. At least one of the advanced courses must be a lecture course 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** In addition to the prerequisites and common degree requirements, 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 of the advanced courses must be a lecture course in the Chemistry department, and at least one must be a Chemistry laboratory course.

**B.S. degree, intensive major** In addition to the prerequisites and common degree requirements, 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 of the advanced courses must be lecture courses in the Chemistry department, and at least one must be a Chemistry laboratory course.

**Combined B.S./M.S. degree program in Chemistry** 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 grades of A or A– earned to continue in the program. The B.S./M.S. degree program requires completion of the intensive major requirements. The introductory physics requirement must be fulfilled with PHYS 200, 201 or 260, 261; a term course in physics numbered 400 or higher and approved by the director of undergraduate studies may be substituted for the introductory sequence. In addition, eight 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 490. Students in the program must earn grades of A in at least two of their graduate-level term courses (or in one year course) and have at least a B average in the remaining ones. B.S./M.S. candidates are also expected to continue their independent research in a summer internship between their junior and senior years. For more information, see “Simultaneous Award of the Bachelor’s and Master’s Degrees” in section K (http://catalog.yale.edu/ycps/academic-regulations/special-arrangements) of the Academic Regulations (http://catalog.yale.edu/ycps/academic-regulations).

**Advanced courses** For the purposes of degree requirements, all undergraduate Chemistry courses numbered 410 or higher count as advanced lecture or laboratory courses, as do CHEM 226L, 251L, and 331L. Because most advanced courses either are offered in full term or have a fall-term course as a prerequisite, students should not plan to take an isolated spring-term advanced course in any given year without first consulting the director of undergraduate studies. Most graduate-level Chemistry courses may also count toward the advanced-course requirement; consult the director of undergraduate studies for information about eligible courses.

**Substitutions for required courses** Up to two terms of advanced science courses outside Chemistry may be counted as electives, with the written approval of the director of undergraduate studies. 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.

**Senior requirement for the B.A. degree** 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 paper is expected to be fifteen to twenty-five pages in length (double-spaced, twelve-point font, exclusive of figures, tables, and bibliography).

**Senior requirement for the B.S. degree** 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 courses. One term of CHEM 490 may be counted as the additional advanced course. The capstone report or essay is expected to be fifteen to twenty-five pages in length (double-spaced, twelve-point font, exclusive of figures, tables, and bibliography). All students performing research must also present their work in the form of an oral or poster presentation as coordinated by the instructor of CHEM 490.

**Senior requirement for the B.S. degree 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 fifteen to twenty-five pages (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 must also present their work in the form of an oral or poster presentation as coordinated by the instructor of CHEM 490.

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

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<tr>
<th>Freshman</th>
<th>Sophomore</th>
<th>Junior</th>
<th>Senior</th>
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<tr>
<td>CHEM 161, 165, 134L, 136L, math prec</td>
<td>CHEM 220, 221, 252, 222L, 223L, physics prec</td>
<td>CHEM 332, 333, 330L, 251L, 1 elective</td>
<td>2 terms of CHEM 490, 2 electives</td>
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**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 includes CHEM 421, Chemical Biology, and two biochemistry electives chosen from MCDB 300, MB&B 300, 301, or selected graduate courses. An inorganic chemistry specialization could include CHEM 450, Physical Methods in Inorganic Chemistry, CHEM 452, Organometallic Chemistry, and CHEM 457, Modern Coordination Chemistry. A program with emphasis in physical chemistry and chemical physics would have three electives chosen from CHEM 430, Statistical Mechanics and Thermodynamics, CHEM 440, Molecules and Radiation I, CHEM 442, Molecules and Radiation II, CHEM 470, Introductory Quantum Chemistry, or a graduate course in quantum mechanics. Students interested in synthetic organic chemistry complete three electives chosen from CHEM 418, Advanced Organic Chemistry I, CHEM 433, Synthetic Methods in Organic Chemistry, CHEM 425, Spectroscopic Methods of Structure Determination, or selected graduate courses. An emphasis in biophysical chemistry includes a course in either chemical biology or biochemistry, as well as two electives chosen...
from graduate courses in biophysics or biochemistry. Students may design programs with other areas of emphasis in consultation with the director of undergraduate studies. For a list of graduate courses appropriate for a particular specialization, consult the director of undergraduate studies.

**Approval of major programs of study** All Chemistry majors in the sophomore, junior, and senior years must have their programs approved by the director of undergraduate studies. A program tailored to each student’s goals is created and recorded on a Chemistry Course of Study form kept on file in the department office. Majors who have a current course of study form on file may have their schedules signed by the director of undergraduate studies or by any of the advisers to the major. A current list of advisers to the major may be obtained in the department office.

**Special restrictions on lecture courses** Chemistry courses may be taken without the accompanying laboratory, although the department does not recommend it. However, the appropriate lecture course is a prerequisite or corequisite for each laboratory course. This restriction can be waived only by the director of undergraduate studies. Students dropping the lecture course corequisite with a laboratory must also drop the laboratory course.

**Year or Term Abroad** In most instances, Chemistry majors find their course of study easier to schedule if they choose to study abroad in 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 section K (http://catalog.yale.edu/ycps/academic-regulations/special-arrangements) of the Academic Regulations.

**REQUIREMENTS OF THE MAJOR**

**Prerequisites** CHEM 161 and 165, or 163 and 167 (or CHEM 112, 113, or 114, 115, or 118); CHEM 134L and 136L (or CHEM 116L, 117L); MATH 115 (MATH 120 or ENAS 151 suggested); PHYS 170, 180, 200, or 260; or equivalents in advanced placement.

**Number of courses**

- **B.A.** – at least 11 term courses, totaling 10 course credits, beyond prereqs (incl senior req).
- **B.S.** – at least 14 term courses, totaling 13 course credits, beyond prereqs (incl senior req).
- **B.S., intensive major** – at least 16 term courses, totaling 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); physical chem I (CHEM 332 or 328); 1 term of inorganic chem (CHEM 185 or 252); B.S. – CHEM 330L, 333; B.S., intensive major – CHEM 330L, 333; PHYS 171, 181, 201, or 261.

**Distribution of courses**

- **B.A. and B.S.** – 4 addtl course credits in advanced lectures or labs, incl at least 1 lecture and 1 lab.
- **B.S., intensive major** – 5 addtl course credits in advanced lectures or labs, incl at least 2 lectures and 1 lab.

**Substitution permitted**

Up to 2 relevant advanced science courses in other depts for advanced chem courses with DUS permission.

**Senior requirement**

- **B.A.** – CHEM 400; **B.S.** – 2 terms of CHEM 490, or CHEM 490 and 1 addtl course credit in advanced lecture or lab; **B.S., intensive major** – 2 terms of CHEM 490.

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**Courses for Nonmajors without Prerequisites**

- **CHEM 102b / ENVE 202b / EVST 102b, Introduction to Green Chemistry**  Paul Anastas

Overview of the basic concepts and methods needed to design processes and synthesize materials in an environmentally benign way. Related issues of global sustainability. Case studies that suggest possible solutions for the serious environmental and toxicological issues currently facing industry and society. Intended for non-science majors with a basic high school background in chemistry and physics, as well as high school algebra. Does not satisfy premedical chemistry requirements or requirements for the Chemistry major.

- **CHEM 104b, Chemistry of Food and Cooking**  Elsa Yan and Narasimhan Ganapathi

Fundamental principles for understanding chemical structures and interactions as well as energy and speed of chemical processes. Application of these principles to food and cooking, including demonstrations.  SC

**Introductory Courses**

Freshmen planning to take an introductory Chemistry course during their first term are required to preregister over the summer. Those planning to elect CHEM 174, 220, or 332 must also register in person and take a placement examination as described in the Chemistry department program description and on the Freshman Web site (http://yalecollege.yale.edu/content/chemistry-1). Placement in other
introductory Chemistry courses is made on the basis of test scores and other admissions data, as discussed in the Chemistry department program description. Time and place for the orientation meeting, registration, and placement examination are listed in the Calendar for the Opening Days of College. For further information on placement see the Freshman Web site (http://yalecollege.yale.edu/content/chemistry-1).

[ CHEM 119L, Laboratory for Quantitative Foundations of General Chemistry ]

CHEM 134La or b, General Chemistry Laboratory I Narasimhan Ganapathi
An introduction to basic chemistry laboratory methods. Techniques required for quantitative analysis of thermodynamic processes and the properties of gases. To accompany or follow CHEM 161 or 163. May not be taken after a higher-numbered laboratory course. SC RP ½ Course cr

CHEM 136La or b, General Chemistry Laboratory II Staff
Introduction to rate and equilibrium measurements, acid-base chemistry, synthesis of inorganic compounds, and qualitative/quantitative analysis. After CHEM 134L or the equivalent in advanced placement. To accompany or follow CHEM 165 or 167. May not be taken after a higher-numbered laboratory course. SC RP ½ Course cr

* CHEM 161a or b, General Chemistry I Staff
A comprehensive survey of modern descriptive, inorganic, and physical chemistry. Atomic theory, stoichiometry, thermochemistry, chemical periodicity, concepts in chemical bonding, and the shapes of molecules. Appropriate either as a first chemistry course or for students with one year of high school chemistry. Attendance at a weekly discussion section required. Normally accompanied by CHEM 134L. Enrollment by placement only. QR, SC RP

* CHEM 163a, Comprehensive University Chemistry I James Mayer and Jonathan Parr
A comprehensive survey of modern descriptive, inorganic, and physical chemistry. Atomic theory, stoichiometry, thermochemistry, chemical periodicity, concepts in chemical bonding, and the shapes of molecules. For students with a good secondary school exposure to general chemistry. Attendance at a weekly discussion section required. Normally accompanied by CHEM 134L. Enrollment by placement only. QR, SC RP

* CHEM 165b, General Chemistry II Jonathan Parr
Topics include kinetics, chemical equilibrium, acid-base chemistry, free energy and entropy, electrochemistry, and nuclear chemistry. Attendance at a weekly discussion section required. Prerequisite: CHEM 161. Normally accompanied by CHEM 136L. Enrollment by placement only. QR, SC RP

* CHEM 167a or b, Comprehensive University Chemistry II Staff
Topics include kinetics, chemical equilibrium, acid-base chemistry, free energy and entropy, electrochemistry, and nuclear chemistry. Attendance at a weekly discussion section required. Prerequisite: CHEM 163, or with equivalent placement. Normally accompanied by CHEM 136L. Enrollment by placement only. QR, SC RP

* CHEM 174a, Freshman Organic Chemistry I Scott Miller
An introductory course focused on current theories of structure and mechanism in organic chemistry, their development, and their basis in experimental observation. Open to freshmen with excellent preparation in chemistry, mathematics, and physics who have taken the department’s advanced chemistry placement examination. Attendance at a weekly discussion section required. Normally accompanied by CHEM 222L. Enrollment by placement only. SC RP

* CHEM 175b, Freshman Organic Chemistry II Alanna Schepartz
Continuation of CHEM 174. Survey of simple and complex reaction mechanisms, spectroscopy, organic synthesis, and the molecules of nature. Attendance at a weekly discussion section required. After CHEM 174. Normally accompanied by CHEM 223L. Enrollment by placement only. SC RP

Intermediate Courses

* CHEM 220a or b, Organic Chemistry Staff
An introductory course covering the fundamental principles of organic chemistry. The laboratory for this course is CHEM 222L. After college-level general chemistry. Students who have earned a grade lower than C in general chemistry are cautioned that they may not be sufficiently prepared for this course. Usually followed by CHEM 221 or 230. SC RP

CHEM 221a or b, The Organic Chemistry of Life Processes Staff
The principles of organic reactivity and how they form the basis for biological processes. The laboratory for this course is CHEM 223L. After CHEM 220. Students who have earned a grade lower than C in general chemistry are cautioned that they may not be sufficiently prepared for this course. SC RP

CHEM 222La or b, Laboratory for Organic Chemistry I Christine DiMeglio
First term of an introductory laboratory sequence covering basic synthetic and analytic techniques in organic chemistry. Prerequisite: CHEM 136L or equivalent. After or concurrently with CHEM 174 or 220. SC ½ Course cr

CHEM 223La or b, Laboratory for Organic Chemistry II Christine DiMeglio
Second term of an introductory laboratory sequence covering basic synthetic and analytic techniques in organic chemistry. Prerequisite: CHEM 222L. After or concurrently with CHEM 175, 221, or 230. SC ½ Course cr
* CHEM 226Lb, Intensive Advanced Chemistry Laboratory  Christine DiMeglio
An intensive course in advanced chemistry laboratory technique intended to bring the student closer to independent research. Included are an independent laboratory project and presentation, introduction to library research, and training in the use of various analytical techniques. Offered subject to available laboratory space and sufficient enrollment. After CHEM 223L. For enrollment procedures, contact the instructors. WR, SC RP

[ CHEM 230, Organic Chemistry of Biological Pathways ]
CHEM 251Lb, Inorganic Chemistry Laboratory  Jonathan Parr
Introductory laboratory course covering synthetic and physical characterization techniques in inorganic chemistry. Prerequisite: CHEM 119L or 222L; concurrently with or after CHEM 252. SC

CHEM 252b, Introductory Inorganic Chemistry  Robert Crabtree
Principles and applications of modern inorganic chemistry. Introduction to some of the fundamental concepts of solid-state chemistry, coordination chemistry, bioinorganic chemistry, and organometallic chemistry. Prerequisite: college-level general chemistry. After or concurrently with CHEM 220 or by permission of instructor. May not be taken after CHEM 450, 452, or 457. SC RP

CHEM 328a, Physical Chemistry with Applications in the Biological Sciences  Richard Baxter
Physical chemical principles and their application to the chemical and life sciences. Thermodynamics, chemical and biochemical kinetics, solution physical chemistry, electrochemistry, and membrane equilibria. CHEM 332 is preferred for Chemistry majors. Prerequisites: introductory physics, college-level general chemistry, and single-variable calculus, or permission of instructor; MATH 120 or ENAS 151 suggested. May not be taken after CHEM 332. QB, SC RP

CHEM 330L, Laboratory for Physical Chemistry I  Patrick Vaccaro and Narasimhan Ganapathi
Introduction to the tools and techniques of modern experimental physical chemistry, including analog/digital electronics, quantitative measurements of basic thermodynamic properties, and nuclear magnetic resonance spectrometry. After or concurrently with CHEM 328 or 332. Meets on Wednesday, Thursday, and Friday from 1:30 to 2:20 for the first week of the term. SC RP

[ CHEM 331L, Laboratory for Physical Chemistry II ]
* CHEM 332a, Physical Chemistry with Applications in the Physical Sciences I  R. James Cross
A comprehensive survey of modern physical and theoretical chemistry, including topics drawn from thermodynamics, chemical equilibrium, electrochemistry, and kinetics. Prerequisites: introductory physics, college-level general chemistry, and single-variable calculus, or permission of instructor; MATH 120 or ENAS 151 suggested. May not be taken after CHEM 332. QR, SC RP

* CHEM 332b, Physical Chemistry with Applications in the Physical Sciences II  Patrick Vaccaro
Continuation of CHEM 332, including topics drawn from quantum mechanics, atomic/molecular structure, spectroscopy, and statistical thermodynamics. Prerequisite: CHEM 328 or 332, or permission of instructor. Recommended preparation: familiarity with differential equations. QR, SC RP

* CHEM 335Lb, Materials and Biophysical Chemistry Laboratory  Ziad Ganim and Hailiang Wang
A laboratory course covering physical methods and chemical synthesis in materials and biophysical chemistry. Techniques include solution phase synthesis, solid state synthesis, UV-Vis, fluorescence, optical microscopy, SEM, STM, single molecule fluorescence, and optical trapping methods. After two terms of general chemistry with laboratory, or concurrently with CHEM 333. SC

Advanced Courses

* CHEM 400a, Current Chemistry Seminar  Jonathan Parr
Designed to engage students in the Chemistry research-seminar program by providing requisite scientific guidance and a forum for directed discussion. Participants explore current avenues of chemical research as presented orally by the prime movers in the field, thereby exploring the frontiers of current knowledge while still retaining the structured environment of a classroom. May fulfill all or part of the senior requirement for the Chemistry major, as detailed in the program description in the YCPS.

* CHEM 418a, Advanced Organic Chemistry I  William Jorgensen
Concise overview of structure, properties, thermodynamics, kinetics, reactions, and intermolecular interactions for organic molecular systems. Prerequisites: two terms of organic chemistry, CHEM 328 or 332, and CHEM 333. SC RP

CHEM 421a, Chemical Biology  Jason Crawford and Sarah Slavoff
A one-term introduction to the origins and emerging frontiers of chemical biology. Discussion of the key molecular building blocks of biological systems and the history of macromolecular research in chemistry. Prerequisites: two terms of organic chemistry, and BIOL 101 or equivalent; BIOL 102 recommended. SC RP

CHEM 423a, Synthetic Methods in Organic Chemistry  Timothy Newhouse
Survey of practical methods in synthetic organic chemistry. Emphasis on learning how to acquire new information and understand chemical reactivity from a fundamental and mechanistic perspective. Prerequisite: two terms of organic chemistry or permission of instructor. SC RP
[ CHEM 425, Spectroscopic Methods of Structure Determination ]

[ CHEM 426, Computational Chemistry and Biochemistry ]

CHEM 430a, Statistical Mechanics and Thermodynamics  Ziad Ganim
The fundamentals of statistical mechanics developed and used to elucidate gas phase and condensed phase behavior, as well as to establish a microscopic derivation of the postulates of thermodynamics. Topics include ensembles; Fermi, Bose, and Boltzmann statistics; density matrices; mean field theories; phase transitions; chemical reaction dynamics; time-correlation functions; and Monte Carlo and molecular dynamics simulations. Prerequisites: CHEM 328 or 332, and CHEM 333, or permission of instructor.  QR, SC  RP

CHEM 437a, Chemistry of Isotopes  Martin Saunders
Advanced applications of isotopes to chemical problems and the theory associated with them, including kinetic and equilibrium isotope effects, tracer applications, and dating.  RP

CHEM 440a, Molecules and Radiation I  Kurt Zilm
An integrated treatment of quantum mechanics and modern spectroscopy. Basic wave and matrix mechanics, perturbation theory, angular momentum, group theory, time-dependent quantum mechanics, selection rules, coherent evolution in two-level systems, line shapes, Bloch equations, and NMR spectroscopy. Prerequisite: CHEM 333 or permission of instructor.  QR, SC  RP

CHEM 442b, Molecules and Radiation II  Mark Johnson
An extension of the material covered in CHEM 440 to atomic and molecular spectroscopy, including rotational, vibrational, and electronic spectroscopy, as well as an introduction to laser spectroscopy. Prerequisite: CHEM 440 or permission of instructor.  QR, SC  RP

[ CHEM 450, Physical Methods in Inorganic Chemistry ]

CHEM 452a, Organometallic Chemistry  Robert Crabtree
A survey of the organometallic chemistry of the transition elements and of homogeneous catalysis. May be taken independently of CHEM 450. Prerequisites: two terms of organic chemistry and CHEM 252.  SC  RP

CHEM 457a, Modern Coordination Chemistry  Nilay Hazari
The principles of modern inorganic chemistry. Main group and transition element chemistry: reactions, bonding, structure, and spectra. Prerequisite: CHEM 252 or permission of instructor.  SC  RP

CHEM 470b, Quantum Chemistry  Victor Batista
The elements of quantum mechanics developed and illustrated with applications in chemistry and chemical physics. Prerequisites: CHEM 333, and MATH 120 or ENAS 151.  QR, SC  RP

* CHEM 490a or b, Independent Research in Chemistry  Jonathan Parr
After consulting with the director of undergraduate studies no later than the last week of the preceding academic term, students choose to work on individual laboratory and/or theoretical research problems under the supervision of a faculty member in Chemistry or in a closely related field of molecular science. Mandatory class meetings address issues of essential laboratory safety and ethics in science, with other class sessions focusing on core topics of broad interest including chemistry literature searching, oral presentation skills, and effective scientific writing. At least ten hours of research required per week. May be taken multiple times for credit. For each term of enrollment, students must complete a CHEM 490 registration form, have it signed by their research adviser and the course instructor, and submit it to the director of undergraduate studies for final approval no later than the last week of the preceding term.  RP

GRADUATE COURSES OF INTEREST TO UNDERGRADUATES

Graduate courses in chemistry that may be of particular interest to undergraduates are listed in the online bulletin (http://www.yale.edu/printer/bulletin/htmlfiles/grad) of the Graduate School. Information about them is available in the office of the director of undergraduate studies. Enrollment requires permission of both the director of graduate studies and the instructor.