CHEMISTRY

Courses offered by the Department are listed under the subject code CHEM on the (http://explorecourses.stanford.edu/CourseSearch/search/?view=catalog&catalog=&page=0&q=CHEM&filter-catalognumber-CHEM=on) Stanford Bulletin's (http://explorecourses.stanford.edu/CourseSearch/search/?view=catalog&catalog=&page=0&q=CHEM&filter-catalognumber-CHEM=on) ExploreCourses web site (http://explorecourses.stanford.edu/CourseSearch/search/?view=catalog&catalog=&page=0&q=CHEM&filter-catalognumber-CHEM=on).

For further information about the Department of Chemistry, see the department's web site (https://chemistry.stanford.edu/).

Chemistry is about the nature of matter, how to make it, how to measure it, how to model it. In that sense chemistry really matters; it is essential to explaining all the real world. It holds the key to making new drugs, creating new materials, and understanding and controlling material properties of all sorts. It is no wonder then that chemistry is called the "Central Science." Traditionally, it is divided into subdisciplines, such as organic, inorganic, physical, biological, theoretical, and analytical, but these distinctions blur as it is increasingly appreciated how all of science, let alone chemistry, is interconnected.

A deeper understanding of chemistry enables students to participate in research and studies involving biotechnology, nanotechnology, catalysis, human health, materials, earth and environmental sciences, and more. Together, faculty, postdoctoral scholars, graduate and undergraduate students actively work side by side developing new probes of biological molecules, modeling protein folding and reactivity, manipulating carbon nanotubes, developing new oxidation and polymerization catalysts, and synthesizing organic molecules to probe ion-channels. The overarching theme of these pursuits is a focus at the atomic and molecular levels, whether this concerns probing the electronic structure and reactivity of molecules as small as dihydrogen or synthesizing large polymer assemblies. The ability to synthesize new molecules and materials and to modify existing biological structures allows the properties of complex systems to be analyzed and harnessed with huge benefit to both the scientific community and society at large.

Undergraduate Program

Mission

The mission of the undergraduate program in Chemistry is to provide students with foundational knowledge in the subdisciplines of chemistry as well as depth in one or more advanced areas, including cutting-edge research. Introductory course work allows students to gain hands-on experience with chemical phenomena, gather data, and propose models and explanations for their observations, thus participating in the scientific process from the start. In advanced labs and lectures, students build an in-depth knowledge of the molecular principles of chemistry empowering them to become molecular engineers comfortable with the methodologies necessary to solve complex problems and effectively articulate their ideas to the scientific community. Ultimately the analytical thinking and problem solving skills developed within the chemistry major make students successful candidates for a wide range of careers in chemistry and beyond, including engineering, teaching, consulting, medicine, law, science writing, and science policy.

Learning Outcomes (Undergraduate)

The department expects undergraduate majors in the program to be able to demonstrate the following learning outcomes. These learning outcomes are used in evaluating students and the department's undergraduate program. Students are expected to:

1. demonstrate the knowledge and skills required to solve problems in the synthesis, measurement, and modeling of chemical systems.
2. apply this set of chemical knowledge and skills to analyze scientific data, evaluate and interpret its significance, and articulate conclusions supportable by the data.
3. be able to construct a scientific hypothesis and devise appropriate experiments to test and evaluate this hypothesis.
4. communicate scientific research effectively in written and spoken form.

Placement Test for First-Year Undergraduates

All students who are interested in taking general chemistry at Stanford must take the Autumn 2020 General Chemistry Placement Test before Autumn quarter begins, regardless of chemistry background. See How To Choose Your First Class (https://chemistry.stanford.edu/academics/undergraduate-program/how-choose-your-first-class/) for further details on the Placement Test.

Graduate Program

The University's basic requirements for the M.S. and Ph.D. degrees are discussed in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees/)" section of this bulletin.

GRE Admissions Requirement

The general GRE and subject test in Chemistry are optional for 2020, but strongly recommended as part of the admissions application for the Ph.D. in Chemistry.

Learning Outcomes (Graduate)

The purpose of the master's program is to further develop knowledge and skills in Chemistry and to prepare students for a professional career or doctoral studies. This is achieved through completion of courses, in the primary field as well as related areas, and experience with independent work and specialization.

The Ph.D. is conferred upon candidates who have demonstrated substantial scholarship and the ability to conduct independent research and analysis in the field of chemistry. Through completion of advanced course work and rigorous skills training, the doctoral program prepares students to make original contributions to the knowledge of chemistry and to interpret and present the results of such research.

Fellowships and Scholarships

In addition to University and school fellowships and scholarships open to properly qualified students, there are several department fellowships in chemistry awarded based on merit. Teaching assistantships and research assistantships are provided to eligible graduate students. Teaching assistantships beyond the required quarters are available for those interested. Graduate fellowships, scholarships, and teaching assistantships are administered through the Department of Chemistry student services office.

Teaching Credentials

The requirements for certification to teach chemistry in the secondary schools of California may be ascertained by consulting the section on credentials under the "Graduate School of Education, Masters, Stanford Teacher Education Program (STEP) (http://exploredegrees.stanford.edu/schoolofeducation/#masterstext)" section of this bulletin and the credential administrator of the School of Education.

Chemical Physics

Students with an exceptionally strong background in physics and mathematics may, with special arrangement, pursue a program of studies in chemical physics.

Bachelor of Science in Chemistry

The Department of Chemistry offers a Bachelor of Science in Chemistry. Eligible students may also pursue a Bachelor of Science with Honors (p. 4). The department also offers a minor in Chemistry (http://exploredegrees.stanford.edu/schoolofhumanitiesandsciences/chemistry/schoolofhumanitiesandsciences/chemistry/#minortext).

The Bachelor of Science in Chemistry is listed as the official major on the transcript and on the diploma. Students may elect to pursue an unofficial concentration in Biological Chemistry. This unofficial concentration is not listed on the transcript nor on the diploma.

Degree Requirements

Additional information on the undergraduate program can be found on the Department of Chemistry website under Academics beginning with the section on the major for the B.S. Degree (https://chemistry.stanford.edu/academics/undergraduate-program/major/).

All degree courses must be taken for a letter grade.

Course Requirements

Students entering (i.e., matriculating) Stanford in Autumn 2019 and later are required to complete CS 106A Programming Methodology prior to CHEM 131 and CHEM 171. MATH 53 is not a requirement for students who entered Stanford in Autumn 2019 and later.

Lab Courses

For those entering the program above CHEM 33, the short course CHEM 100 Chemical Laboratory and Safety Skills is required; this course is only offered the second week of Autumn Quarter (not offered or required in AY 2020-21).

Lab courses have a mandatory, non-refundable fee. Students must obtain a department-approved lab coat and safety glasses. The department makes these available for purchase at the lowest possible price during the first few days of each quarter.

Traditional Chemistry Concentration

Requirements for students who entered Stanford in Autumn 2020 and later. For more senior students, consult the Bulletin (http://exploredegrees.stanford.edu/archive/#text) matching the year of matriculation (i.e., starting at) Stanford.

		Units
Introductory Courses		
Select one of the following:		5-10
CHEM 31A & CHEM 31B	Chemical Principles I and Chemical Principles II (5 units each)	
CHEM 31M	Chemical Principles: From Molecules to Solids (5 units)	5
CHEM 33	Structure and Reactivity of Organic Molecules	5
Foundational Courses		
CHEM 121	Understanding the Natural and Unnatural World through Chemistry	5
CHEM 131	Instrumental Analysis Principles and Practice	5
CHEM 151	Inorganic Chemistry I	4
CHEM 171	Foundations of Physical Chemistry	4
CS 106A	Programming Methodology	5
MATH 19	Calculus	3
MATH 20	Calculus	3
MATH 21	Calculus	4
MATH 51	Linear Algebra, Multivariable Calculus, and Modern Applications	5
PHYSICS 41	Mechanics	4
PHYSICS 42	Classical Mechanics Laboratory	1
PHYSICS 43	Electricity and Magnetism	4
PHYSICS 44	Electricity and Magnetism Lab	1
Advanced Courses		
CHEM 123	Organic Polyfunctional Compounds	3
CHEM 124	Organic Chemistry Laboratory	3
CHEM 126	Synthesis Laboratory	3
CHEM 153	Inorganic Chemistry II	3
CHEM 173	Physical Chemistry II	3
CHEM 174	Electrochemical Measurements Lab	3
CHEM 175	Physical Chemistry III	3
CHEM 176	Spectroscopy Laboratory	3
Total Units		87-92

Biological Chemistry Concentration

Requirements for students entering Stanford Autumn 2019 and later. For more senior students, consult the Bulletin (http://exploredegrees.stanford.edu/archive/#text) matching the year of matriculation (i.e., starting at) Stanford. The graduate-level elective course requirement has been dropped for all students.

		Units
Introductory Courses		
Select one of the following:		5-10
CHEM 31A & CHEM 31B	Chemical Principles I and Chemical Principles II (5 units each)	
CHEM 31M	Chemical Principles: From Molecules to Solids	5
CHEM 33	Structure and Reactivity of Organic Molecules	5
Foundational Courses		
CHEM 121	Understanding the Natural and Unnatural World through Chemistry	5
CHEM 131	Instrumental Analysis Principles and Practice	5
CHEM 151	Inorganic Chemistry I	4
CHEM 171	Foundations of Physical Chemistry	4
CHEM 181	Biochemistry I	4
Select one of the following BIO courses:		4
BIO 82	Genetics (4 units)	
BIO 84	Physiology (4 units)	
BIO 86	Cell Biology (4 units)	
CS 106A	Programming Methodology	5
MATH 19	Calculus	3
MATH 20	Calculus	3
MATH 21	Calculus	4
MATH 51	Linear Algebra, Multivariable Calculus, and Modern Applications	5
PHYSICS 41	Mechanics	4
PHYSICS 42	Classical Mechanics Laboratory	1
PHYSICS 43	Electricity and Magnetism	4
PHYSICS 44	Electricity and Magnetism Lab	1
Advanced Courses		
CHEM 123	Organic Polyfunctional Compounds	3
CHEM 124	Organic Chemistry Laboratory	3
CHEM 126	Synthesis Laboratory	3

CHEM 173	Physical Chemistry II	3
CHEM 176	Spectroscopy Laboratory	3
CHEM 183	Biochemistry II	3
CHEM 184	Biological Chemistry Laboratory	3
CHEM 185	Biophysical Chemistry	3
Total Units		95-100

Additional Information

Chemistry Major Schedule

Below are possible schedules for students entering Stanford in Autumn 2019 and later wanting to complete the traditional concentration and the biological chemistry concentration, each followed by an accelerated schedule.

Schedule for Traditional Chemistry Concentration

First Year	Units		
	Autumn	Winter	Spring
Chemical Principles I (CHEM 31A)	5		
Calculus (MATH 19)	3		
Chemical Principles II (CHEM 31B)		5	
Calculus (MATH 20)		3	
Programming Methodology (CS 106A)		5	
Structure and Reactivity of Organic Molecules (CHEM 33)			5
Calculus (MATH 21)			4
Year Total:	8	13	9

Second Year	Units		
	Autumn	Winter	Spring
Understanding the Natural and Unnatural World through Chemistry (CHEM 121)	5		
Linear Algebra, Multivariable Calculus, and Modern Applications (MATH 51)	5		
Inorganic Chemistry I (CHEM 151)		4	
Mechanics (PHYSICS 41)		4	
Classical Mechanics Laboratory (PHYSICS 42)		1	
Instrumental Analysis Principles and Practice (CHEM 131)			5
Foundations of Physical Chemistry (CHEM 171)			4
Year Total:	10	9	9

Third Year	Units		
	Autumn	Winter	Spring
Organic Polyfunctional Compounds (CHEM 123)	3		
Organic Chemistry Laboratory (CHEM 124)	3		
Synthesis Laboratory (CHEM 126)		3	
Electricity and Magnetism (PHYSICS 43)			4
Electricity and Magnetism Lab (PHYSICS 44)			1
Year Total:	6	3	5

Fourth Year	Units		
	Autumn	Winter	Spring
Physical Chemistry II (CHEM 173)	3		
Electrochemical Measurements Lab (CHEM 174)	3		
Physical Chemistry III (CHEM 175)		3	
Spectroscopy Laboratory (CHEM 176)		3	
Inorganic Chemistry II (CHEM 153)			3
Year Total:	6	6	3

Total Units in Sequence:	87

Accelerated Schedule for the Traditional Chemistry Concentration

First Year	Units		
	Autumn	Winter	Spring
Chemical Principles: From Molecules to Solids (CHEM 31M)	5		
Programming Methodology (CS 106A)	5		
Structure and Reactivity of Organic Molecules (CHEM 33)		5	
Mechanics (PHYSICS 41)		4	
Classical Mechanics Laboratory (PHYSICS 42)		1	
Understanding the Natural and Unnatural World through Chemistry (CHEM 121)			5
Electricity and Magnetism (PHYSICS 43)			4
Electricity and Magnetism Lab (PHYSICS 44)			1
Year Total:	10	10	10

Second Year	Units		
	Autumn	Winter	Spring
Organic Polyfunctional Compounds (CHEM 123)	3		
Organic Chemistry Laboratory (CHEM 124)	3		
Linear Algebra, Multivariable Calculus, and Modern Applications (MATH 51)	5		
Synthesis Laboratory (CHEM 126)		3	
Inorganic Chemistry I (CHEM 151)		4	
Instrumental Analysis Principles and Practice (CHEM 131)			5
Foundations of Physical Chemistry (CHEM 171)			4
Year Total:	11	7	9

Third Year	Units		
	Autumn	Winter	Spring
Physical Chemistry II (CHEM 173)	3		
Electrochemical Measurements Lab (CHEM 174)	3		
Physical Chemistry III (CHEM 175)		3	
Spectroscopy Laboratory (CHEM 176)		3	
Inorganic Chemistry II (CHEM 153)			3
Year Total:	6	6	3

Total Units in Sequence:	72

Schedule for Biological Chemistry Concentration

First Year	Units		
	Autumn	Winter	Spring
Chemical Principles I (CHEM 31A)	5		
Calculus (MATH 19)	3		
Chemical Principles II (CHEM 31B)		5	
Calculus (MATH 20)		3	
Programming Methodology (CS 106A)		5	
Structure and Reactivity of Organic Molecules (CHEM 33)			5
Calculus (MATH 21)			4
Year Total:	8	13	9

Second Year	Units		
	Autumn	Winter	Spring
Understanding the Natural and Unnatural World through Chemistry (CHEM 121)	5		
Linear Algebra, Multivariable Calculus, and Modern Applications (MATH 51)	5		
Inorganic Chemistry I (CHEM 151)		4	
Mechanics (PHYSICS 41)		4	
Classical Mechanics Laboratory (PHYSICS 42)		1	
Instrumental Analysis Principles and Practice (CHEM 131)			5
Foundations of Physical Chemistry (CHEM 171)			4
Year Total:	10	9	9

Third Year	Units		
	Autumn	Winter	Spring
Biochemistry I (CHEM 181)	4		
Organic Polyfunctional Compounds (CHEM 123)	3		
Organic Chemistry Laboratory (CHEM 124)	3		
Synthesis Laboratory (CHEM 126)		3	
Biochemistry II (CHEM 183)		3	
Physiology (BIO 84)		4	
Biological Chemistry Laboratory (CHEM 184)			3
Electricity and Magnetism (PHYSICS 43)			4
Electricity and Magnetism Lab (PHYSICS 44)			1
Year Total:	10	10	8

Fourth Year	Units		
	Autumn	Winter	Spring
Physical Chemistry II (CHEM 173)	3		
Spectroscopy Laboratory (CHEM 176)		3	
Biophysical Chemistry (CHEM 185)			3
Year Total:	3	3	3

Total Units in Sequence:	95

Accelerated Schedule for the Biological Chemistry Concentration

First Year	Units		
	Autumn	Winter	Spring
Chemical Principles: From Molecules to Solids (CHEM 31M)	5		
Programming Methodology (CS 106A)	5		
Structure and Reactivity of Organic Molecules (CHEM 33)		5	
Mechanics (PHYSICS 41)		4	
Classical Mechanics Laboratory (PHYSICS 42)		1	
Understanding the Natural and Unnatural World through Chemistry (CHEM 121)			5
Electricity and Magnetism (PHYSICS 43)			4
Electricity and Magnetism Lab (PHYSICS 44)			1
Year Total:	10	10	10

Second Year	Units		
	Autumn	Winter	Spring
Organic Polyfunctional Compounds (CHEM 123)	3		
Organic Chemistry Laboratory (CHEM 124)	3		
Linear Algebra, Multivariable Calculus, and Modern Applications (MATH 51)	5		
Inorganic Chemistry I (CHEM 151)		4	
Synthesis Laboratory (CHEM 126)		3	
Physiology (BIO 84)		4	
Instrumental Analysis Principles and Practice (CHEM 131)			5
Foundations of Physical Chemistry (CHEM 171)			4
Year Total:	11	11	9

Third Year	Units		
	Autumn	Winter	Spring
Physical Chemistry II (CHEM 173)	3		
Biochemistry I (CHEM 181)	4		
Spectroscopy Laboratory (CHEM 176)		3	
Biochemistry II (CHEM 183)		3	
Biological Chemistry Laboratory (CHEM 184)			3
Biophysical Chemistry (CHEM 185)			3
Year Total:	7	6	6

Total Units in Sequence:	80

Related Courses

Courses offered by other departments that may be of interest to Chemistry majors include:

		Units
BIO 82	Genetics	4
BIO 84	Physiology	4
BIO 86	Cell Biology	4
CHEMENG 20	Introduction to Chemical Engineering	4
CHEMENG 100	Chemical Process Modeling, Dynamics, and Control	3
CHEMENG 110B	Multi-Component and Multi-Phase Thermodynamics	3
CHEMENG 120A	Fluid Mechanics	4
CHEMENG 120B	Energy and Mass Transport	4
CS 106B	Programming Abstractions	3-5
CHEMENG 130A	Microkinetics - Molecular Principles of Chemical Kinetics	3
ENGR 50	Introduction to Materials Science, Nanotechnology Emphasis	4
MATH 106	Functions of a Complex Variable	3
MATH 109	Applied Group Theory	3
MATH 113	Linear Algebra and Matrix Theory	3
MATH 131P	Partial Differential Equations	3
MATSCI 151	Microstructure and Mechanical Properties	4
PHYSICS 110	Advanced Mechanics	4
STATS 110	Statistical Methods in Engineering and the Physical Sciences	5
STATS 116	Theory of Probability	4

Honors Program

A bachelor's degree in Chemistry with honors is available to those students interested in chemical research. Admission to the honors program requires a grade point average (GPA) of 3.3 in science courses and an overall GPA of 3.0 in all University courses. Beyond the standard B.S. course requirements for each track, 9 units of research credit and 9 units of course work need to be completed during the junior and senior academic years. A thesis, approved by the honors advisor, must be completed during the senior year. The thesis must be submitted to the research advisor, at least one week before the end of regular classes in Spring Quarter, and must be completed by May 15 to be considered for the Firestone award. The use of a single course for multiple requirements for honors, major, minor, or coterminal requirements is not allowed. Students who wish to be admitted to the honors program should register with the Student Services Manager in Spring Quarter of their junior year.

CHEM 190 Advanced Undergraduate Research research units towards honors may be completed, after being accepted into the program, in any laboratory within Chemistry or with courtesy faculty in Chemistry. Other chemical research can be approved through a formal petitioning of the Undergraduate Studies Committee. At least 3 units must be completed during the senior year. Participation in a summer research program in an academic setting between junior and senior years may be used in lieu of 3 units of CHEM 190 Advanced Undergraduate Research. For each quarter, a progress report reflecting the units undertaken is required. This report must be signed by the honors advisor, and filed in the department student services office before the last day of finals in the quarter during which the research is performed.

The 9 units of course work for honors must be completed from courses approved by the Undergraduate Studies Committee and taken for a letter grade. At least six of these units need to be taken from the following CHEM courses:

		Units
CHEM 153	Inorganic Chemistry II	3
CHEM 174	Electrochemical Measurements Lab	3
CHEM 175	Physical Chemistry III	3
CHEM 181	Biochemistry I	4
CHEM 183	Biochemistry II	3
CHEM 184	Biological Chemistry Laboratory	3
CHEM 185	Biophysical Chemistry	3
CHEM 221	Advanced Organic Chemistry I	3
CHEM 223	Advanced Organic Chemistry II	3
CHEM 225	Advanced Organic Chemistry III (not offered in AY2020-21)	3
CHEM 232	Applications of NMR Spectroscopy	3
CHEM 251	Advanced Inorganic Chemistry	3
CHEM 253	Fundamentals of Inorganic Chemistry (not offered in AY2020-21)	3
CHEM 255	Advanced Inorganic Chemistry (not offered in AY2020-21)	3
CHEM 257	Bio-Inorganic Chemistry (not offered in AY2020-21)	3
CHEM 261	Computational Chemistry (not offered in AY2020-21)	3
CHEM 271	Advanced Physical Chemistry	3
CHEM 273	Advanced Physical Chemistry	3
CHEM 275	Advanced Physical Chemistry - Single Molecules and Light	3
CHEM 277	Materials Chemistry and Physics (not offered in AY2020-21)	3
CHEM 281	Therapeutic Science at the Chemistry - Biology Interface	3
CHEM 283	Synthesis and Analysis at the Chemistry-Biology Interface	3
CHEM 289	Concepts and Applications in Chemical Biology	3

Minor in Chemistry

Courses required for a minor must be taken for a letter grade and all courses below are required:

		Units
CHEM 33	Structure and Reactivity of Organic Molecules	5
CHEM 121	Understanding the Natural and Unnatural World through Chemistry	5
CHEM 123	Organic Polyfunctional Compounds	3
CHEM 124	Organic Chemistry Laboratory	3
CHEM 131	Instrumental Analysis Principles and Practice	5
CHEM 151	Inorganic Chemistry I	4
CHEM 171	Foundations of Physical Chemistry	4
Total Units		29

Master of Science in Chemistry

The Master of Science is available only to current Ph.D. students or as part of a coterminal program. Applicants for the M.S. degree in Chemistry are required to complete, in addition to the requirements for the bachelor's degree, a minimum of 45 graduate-level units and a M.S. thesis. Of the 45 units, approximately two-thirds must be in the department and must include at least 12 units of graduate level lecture courses exclusive of the thesis.

University Coterminal Requirements

Coterminal master's degree candidates are expected to complete all master's degree requirements as described in this bulletin. University requirements for the coterminal master's degree are described in the "Coterminal Master's Program (http://exploredegrees.stanford.edu/cotermdegrees/)" section. University requirements for the master's degree are described in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees/#masterstext)" section of this bulletin.

After accepting admission to this coterminal master's degree program, students may request transfer of courses from the undergraduate to the graduate career to satisfy requirements for the master's degree. Transfer of courses to the graduate career requires review and approval of both the undergraduate and graduate programs on a case by case basis.

In this master's program, courses taken three quarters prior to the first graduate quarter, or later, are eligible for consideration for transfer to the graduate career. No courses taken prior to the first quarter of the sophomore year may be used to meet master's degree requirements.

Course transfers are not possible after the bachelor's degree has been conferred.

The University requires that the graduate advisor be assigned in the student's first graduate quarter even though the undergraduate career may still be open. The University also requires that the Master's Degree Program Proposal be completed by the student and approved by the department by the end of the student's first graduate quarter.

		Units
Of the 12 units, at least 6 units must be from:		
CHEM 221	Advanced Organic Chemistry I	3
CHEM 223	Advanced Organic Chemistry II	3
CHEM 225	Advanced Organic Chemistry III	3
CHEM 232	Applications of NMR Spectroscopy	3
CHEM 251	Advanced Inorganic Chemistry	3
CHEM 253	Fundamentals of Inorganic Chemistry	3
CHEM 255	Advanced Inorganic Chemistry	3
CHEM 257	Bio-Inorganic Chemistry	3
CHEM 261	Computational Chemistry	3
CHEM 271	Advanced Physical Chemistry	3
CHEM 273	Advanced Physical Chemistry	3
CHEM 275	Advanced Physical Chemistry - Single Molecules and Light	3
CHEM 277	Materials Chemistry and Physics	3
CHEM 281	Therapeutic Science at the Chemistry - Biology Interface	3
CHEM 283	Synthesis and Analysis at the Chemistry-Biology Interface	3
CHEM 285	Biophysical Chemistry	3

Doctor of Philosophy in Chemistry

Process to Candidacy

Graduate students are eligible to become formal candidates for the Ph.D. degree after taking the department placement examinations, satisfactory completion of most of the formal lecture course requirements, and satisfactory progress on a dissertation research project determined by passing a progress report with one's thesis committee. There is no foreign language requirement for the Ph.D. degree. Admission to candidacy for the Ph.D. degree must be done before July of the second year of graduate registration.

Placement Examinations

Each new graduate student must take placement examinations upon entrance. These consist of three written examinations of two hours each in the fields of inorganic, organic, and physical chemistry, and cover such material as ordinarily is given in a rigorous one-year undergraduate course in each of these subjects. Students concentrating in biophysical chemistry or chemical physics must take examinations in biophysical or chemical physics, physical chemistry, and organic or inorganic chemistry. Students concentrating in chemical biology must take examinations in biophysical, organic chemistry, and physical chemistry or inorganic chemistry. All placement examinations are given the week before instruction begins in Autumn Quarter, and must be taken at that time. Each new graduate student meets with a member of the graduate study committee to define a program of courses based on results of the placement examinations.

General Requirements

After taking the departmental placement examinations, students select a research advisor by interviewing members of the Chemistry faculty. An Application to Start Research form is submitted to the Department as research begins under the supervision of the advisor. All students in good standing are required to start research by the end of February, during Winter Quarter of the first year of graduate registration.

Candidates for the Ph.D. degree are required to participate continually in the department colloquium (CHEM 300 Department Colloquium) and in the division seminar of the major subject (CHEM 329 Organic Chemistry Seminar, CHEM 359 Inorganic Chemistry Seminar, or CHEM 379 Physical Chemistry Seminar).

Candidates for advanced degrees must have a minimum grade point average (GPA) of 3.0 for all Chemistry lecture courses as well as for all courses taken during graduate study. Required courses must be taken for a letter grade. Most course work ends in the second year of studies, and students will then focus on full-time dissertation research.

Students may major in organic, chemical biology, physical, biophysical, chemical physics, or inorganic chemistry. All graduate students are required to take six graduate-level lecture courses (course numbers greater than 199) of at least 3 units each in chemistry or related disciplines (e.g., biochemistry, electrical engineering, mathematics, chemical engineering, chemical and systems biology, physics, materials science), to be selected in consultation with their research advisor and the Graduate Study Committee. All six courses must be taken for a letter grade. At least three of the six courses must be taken within the Chemistry Department. A minimum of four courses should be completed by the end of the first year.

Course Requirements for entering classes beginning with 2018-19

		Units
All students must complete:		
CHEM 211A	Research Progress in Chemistry (in the second year)	1
CHEM 211B	Chemistry Research Seminar Presentation (in the third year)	1
CHEM 211C	Chemistry Research Proposal (in the fourth year)	1
Students majoring in physical or biophysical chemistry or chemical physics must also complete:		
CHEM 271	Advanced Physical Chemistry (in the first year)	3
CHEM 273	Advanced Physical Chemistry (in the first year)	3

Course Requirements for entering classes prior to 2018-19

Requirements for students who entered Stanford prior to 2018-19, please consult the Bulletin (http://exploredegrees.stanford.edu/archive/#text) matching the year of matriculation (i.e., starting at) Stanford.

Continuous enrollment in CHEM 301 Research in Chemistry is expected after the student has chosen a research supervisor.

Post-Candidacy

Before candidates may request scheduling of the University oral examination, clearance must be obtained from the dissertation advisor and an academic review meeting made with the Student Services Manager for the Department of Chemistry.

During the period in which a dissertation is being read by members of the faculty, candidates must be available for personal consultation until the dissertation has received final department approval.

Ph.D. Minor in Chemistry

Candidates for the Ph.D. degree in other departments who wish to obtain a minor in chemistry must complete, with a GPA of 3.0 or higher, 20 graduate-level units in Chemistry including four lecture courses of at least three units each.

COVID-19 Policies

On July 30, the Academic Senate adopted grading policies effective for all undergraduate and graduate programs, excepting the professional Graduate School of Business, School of Law, and the School of Medicine M.D. Program. For a complete list of those and other academic policies relating to the pandemic, see the "COVID-19 and Academic Continuity (http://exploredegrees.stanford.edu/covid-19-policy-changes/#tempdepttemplatetabtext)" section of this bulletin.

The Senate decided that all undergraduate and graduate courses offered for a letter grade must also offer students the option of taking the course for a “credit” or “no credit” grade and recommended that deans, departments, and programs consider adopting local policies to count courses taken for a “credit” or “satisfactory” grade toward the fulfillment of degree-program requirements and/or alter program requirements as appropriate.

Undergraduate Degree Requirements

Grading

The Chemistry Undergraduate Program has changed its policy concerning 'CR' (credit) and 'S' (satisfactory) grades in degree requirements. The program will accept letter, 'CR', or 'S' grades for all major and minor course work for academic year 2020-21.

Graduate Degree Requirements

Grading

The Department of Chemistry has not changed its policy concerning 'CR' (credit) or 'S' (satisfactory) grades in graduate degree requirements requiring a letter grade for academic year 2020-21.

Graduate Advising Expectations

The Department of Chemistry is committed to providing academic advising in support of graduate student scholarly and professional development. This advising relationship entails collaborative and sustained engagement with mutual respect by both the advisor and advisee.

1. The advisor is expected to meet at least monthly with the graduate student to discuss on-going research.
2. There should be a yearly independent development plan (IDP) meeting between the graduate student and advisor. Topics include research progress, expectations for completion of Ph.D., areas for both the student and advisor to improve in their joint research effort.
3. A research advisor should provide timely feedback on manuscripts and thesis chapters.
4. Graduate students are active contributors to the advising relationship, proactively seeking academic and professional guidance and taking responsibility for informing themselves of policies and degree requirements for their graduate program.
5. If there is a significant issue concerning the graduate student's progress in research, the advisor must communicate this to the student and to the Graduate Studies Committee in writing. This feedback should include the issues, what needs to be done to overcome these issues, and by when.

For a statement of University policy on graduate advising, see the "Graduate Advising (http://exploredegrees.stanford.edu/graduatedegrees/#advisingandcredentialstext)" section of this bulletin. Academic advising by Stanford faculty is a critical component of all graduate students' education and additional resources can be found in the Policies and Best Practices for Advising Relationships at Stanford (http://stanford.box.com/shared/static/73oj7zqvy9h0fezqf310onbuunv91nyl.pdf) and the Guidelines for Faculty-Student Advising at Stanford (https://stanford.box.com/shared/static/mespm59bcanq03o4pppu7r4n9p4sb6t6.pdf).

Emeriti: (Professors) Hans C. Andersen, John I. Brauman, James P. Collman, Wray H. Huestis, Robert Pecora, Barry M. Trost

Chair: Steven G. Boxer

Vice Chair: T. Daniel P. Stack

Director of Graduate Studies: Edward I. Solomon

Director of Undergraduate Studies: Christopher E. D. Chidsey

Professors: Steven G. Boxer, Carolyn R. Bertozzi, James K. Chen, Bianxiao Cui, Hongjie Dai, Justin Du Bois, Michael D. Fayer, Keith O. Hodgson, Chaitan Khosla, Eric T. Kool, Todd J. Martínez, W. E. Moerner, Edward I. Solomon, Robert M. Waymouth, Paul A. Wender, Richard N. Zare

Associate Professors: Noah Z. Burns, Lynette Cegelski, Christopher E. D. Chidsey, Matthew Kanan, Hemamala Karunadasa, Thomas E. Markland, T. Daniel P. Stack, Yan Xia

Assistant Professors: Steven M. Banik (start date 1/1/2021), Laura Dassama, Fang Liu, Grant Rotskoff

Courtesy Professors: Zhenan Bao, Stacey F. Bent, Yi Cui, Kelly Gaffney, Jianghong Rao, Andrew Spakowitz, Alice Y. Ting

Adjunct Professors: Christopher Walsh

Lecturers: Megan K. Brennan, Jennifer Schwartz Poehlmann, Kevin Sibucao

Courses

CHEM 10. Exploring Research and Problem Solving Across the Sciences. 1 Unit.
Development and practice of critical problem solving and study skills using a wide variety of scientific examples that illustrate the broad yet integrated nature of current research. Students will build a problem solving tool-kit and apply chemical and mathematical concepts to solve problems related to energy, climate change, water resources, medicine, and food & nutrition. Note: course offered in August prior to start of fall quarter, and only Leland Scholar Program participants will register.

CHEM 25N. Science in the News. 3 Units.
Preference to freshmen. Possible topics include: diseases such as avian flu, HIV, and malaria; environmental issues such as climate change, atmospheric pollution, and human population; energy sources in the future; evolution; stem cell research; nanotechnology; and drug development. Focus is on the scientific basis for these topics as a basis for intelligent discussion of societal and political implications. Sources include the popular media and scientific media for the nonspecialist, especially those available on the web.

CHEM 29N. Chemistry in the Kitchen. 3 Units.
This course examines the chemistry relevant to food and drink preparation, both in homes and in restaurants, which makes what we consume more pleasurable. Good cooking is more often considered an art rather than a science, but a small bit of understanding goes a long way to make the preparation and consumption of food and drink more enjoyable. The intention is to have demonstrations and tastings as a part of every class meeting. We will examine some rather familiar items in this course: eggs, dairy products, meats, breads, vegetables, pastries, and carbonated beverages. We shall playfully explore the chemistry that turns food into meals. A high-school chemistry background is assumed; bring to class a good appetite and a healthy curiosity.

CHEM 31A. Chemical Principles I. 5 Units.
31A is the first course in a two-quarter sequence designed to provide a robust foundation in key chemical principles for students with limited background in chemistry. The course engages students in group problem-solving activities throughout the class periods to deepen their ability to analyze and solve chemical problems. Students will also participate in weekly labs that will apply and expand upon class content. Due to social distancing guidelines, labs will be held over live Zoom. Students can opt-in to receive an at home lab kit that will allow them to conduct low-risk portions of the labs from their location. TAs will demonstrate and guide students through hands-on portions, as well as supplement with further in-depth video labs, virtual simulations, and problem solving practice. n31A will provide practice developing conceptual models that can explain qualitatively and quantitatively a wide range of chemical phenomena and will be immediately applied to real world challenges. Students practice dimensional analysis, stoichiometry, and molecular naming that enables them to write chemical reactions, quantify reaction yield, and calculate empirical and molecular formulas. Using these skills, students estimate carbon efficiency of fossil fuels and identify unknowns in forensic analysis. Stoichiometry is reinforced through study of gases and their properties, through which students calculate the pressure exerted on a deep-sea diver. Students examine atomic and molecular structure by quantifying interactions among nuclei, electrons, atoms and molecules and explain trends in reactivity, such as why potassium metal catches fire in water. They explore how these interactions determine the structures and properties of pure substances, mixtures, proteins, and even DNA using three conceptual models for bonding: Lewis Dot, VSEPR, and Molecular Orbital Theory. They investigate the types and amounts of energy changes that accompany these interactions, phase changes, and chemical reactions, such as measuring the caloric content of food and dissecting an instant hand warmer. By the end of the course, students will be prepared to explore chemical reactivity in greater depth in 31B. nAll students who are interested in taking general chemistry at Stanford must take the Autumn 2020 General Chemistry Placement Test before Autumn quarter begins, regardless of chemistry background. Students with no AP/IB background are given enrollment priority in the 31A/B sequence.

CHEM 31B. Chemical Principles II. 5 Units.
Chem 31B is the second course in this two-quarter sequence, therefore only students who have completed Chem 31A may enroll in 31B. As with 31A, students will continue to engage in group problem-solving activities throughout class and participate in weekly laboratory activities. Labs and write-ups will allow students to more deeply explore and observe the different facets of chemical reactivity, including rates (kinetics), energetics (thermodynamics), and reversibility (equilibrium) of reactions. Through experimentation and discussion, students will determine what forces influence the rate of chemical reactions and learn how this can be applied to enzyme reactivity. Students will quantify chemical concentrations during a reaction, and predict the direction in which a reaction will shift in order to achieve equilibrium, including solubility equilibria. They will use these methods to estimate the possible levels of lead and other toxic metals in drinking water. Special emphasis will be placed on acid/base equilibria , allowing students to explore the role of buffers and antacids in our bodies, as well as ocean acidification and the impact on coral reefs. Students will then bring together concepts from both kinetics and equilibrium, in a deeper discussion of thermodynamics, to understand what ultimately influences the spontaneity of a reaction. Students will build a relationship between free energy, temperature, and equilibrium constants to be able to calculate the free energy of a reaction and understand how processes in our body are coupled to harness excess free energy to do useful work. Finally we will explore how we harness work from redox reactions, building both voltaic cells (i.e. batteries) and electrolytic cells in lab, and using reduction potentials to predict spontaneity and potential of a given reaction. We will look at the applications of redox chemistry in electric and fuel cell vehicles. The course's particular emphasis on understanding the driving forces of a reaction, especially the influence of thermodynamics versus kinetics, will prepare students for further study of predicting organic chemical reactivity and equilibria from structure in Chem 33. Prerequisite: Chem 31A.

CHEM 31M. Chemical Principles: From Molecules to Solids. 5 Units.
A one-quarter course for students who have taken chemistry previously. This course will introduce the basic chemical principles that dictate how and why reactions occur and the structure and properties of important molecules and extended solids that make up our world. As the Central Science, a knowledge of chemistry provides a deep understanding of concepts in fields ranging from materials, environmental science, and engineering to pharmacology and metabolism. Discussions of molecular structure will describe bonding models including Lewis structures, resonance, crystal-field theory, and molecular-orbital theory. We will reveal the chemistry of materials of different dimensionality, with emphasis on symmetry, bonding, and electronic structure of molecules and solids. We will also discuss the kinetics and thermodynamics that govern reactivity and dictate solubility and acid-base equilibria. A two-hour weekly laboratory section accompanies the course to introduce laboratory techniques and reiterate lecture concepts through hands-on activities. Specific discussions will include the structure, properties, and applications of molecules used in medicine, perovskites used in solar cells, and the dramatically different properties of materials with the same composition (for example: diamond, graphite, graphene). There will be three lectures, one two-hour laboratory session, and an optional 80-minute problem solving session each week. The course will assume familiarity with stoichiometry, unit conversions, and gas laws. All students who are interested in taking general chemistry at Stanford must take the Autumn 2020 General Chemistry Placement Test before Autumn quarter begins, regardless of chemistry background. Generally students earning an AP chemistry score of 4 or higher place into 31M. Students earning an AP score of 5 are also welcome to take the Autumn 2020 Chemistry 33 Placement Test to see if Chem33 is a more appropriate placement. Same as: MATSCI 31.
Same as: MATSCI 31

CHEM 33. Structure and Reactivity of Organic Molecules. 5 Units.
An introduction to organic chemistry, the molecular foundation to understanding of life, medicine, imaging, energy, and material science. Students will learn structural and bonding models of organic molecules that provide insights into chemical, physical, and reactivity properties, in addition to their biological activities, collectively contributing to the molecularization and thus advancement of many science disciplines. Combining these models with kinetic and thermodynamic analyses allows molecular conversions to be rationalized. Translation of this knowledge to more complex systems enables the synthesis of novel molecules or materials that can positively impact our science, society and environment. A two-hour weekly lab section accompanies the course to introduce the techniques of separation and identification of organic compounds. Prerequisite: CHEM 31B or CHEM 31M.

CHEM 90. Directed Instruction/Reading. 1-2 Unit.
Undergraduates pursue a reading program under supervision of a faculty member in Chemistry; may also involve participation in lab. Prerequisites: superior work in CHEM 31A, 31B, 31M, 31X, or 33; and consent of instructor.

CHEM 91. Exploring Chemical Research at Stanford. 1 Unit.
Preference to freshmen and sophomores. Department faculty describe their cutting-edge research and its applications.

CHEM 100. Chemical Laboratory and Safety Skills. 1 Unit.
(Not offered in AY 2020-21) This short course is only held in the second week of Autumn quarter. It provides training in basic chemical laboratory procedures and chemical safety to fulfill the safety training requirement for CHEM 121 and more advanced laboratory courses. Includes on-line and in-lab training. Successful completion of all course components required for credit. Prerequisite: introductory organic chemistry.

CHEM 121. Understanding the Natural and Unnatural World through Chemistry. 5 Units.
Students enrolled in this course will appreciate the transformative power of molecular science on the modern world and how foundational knowledge of chemistry enables profound discoveries in biological, pharmaceutical, agrochemical, engineering, energy, and materials science research. This course integrates the lessons of CHEM 31 and CHEM 33 through an examination of the structure-function properties of carbon-based molecules. Specific emphasis is given to the chemistry of carbonyl- and amine-derived compounds, polyfunctionalized molecules, reaction kinetics and thermodynamics, mechanistic arrow-pushing, and retrosynthetic analysis. Students will be empowered with a conceptual understanding of chemical reactivity, physical organic chemistry, and the logic of chemical synthesis. The singular nature of molecular design and synthesis to make available functional molecules and materials will be revealed. A three-hour lab section provides hands on experience with modern chemical methods for preparative and analytical chemistry. Prerequisite CHEM 33 or co-requisite CHEM 100 (not required in AY 2020-21).

CHEM 123. Organic Polyfunctional Compounds. 3 Units.
Analysis of molecular symmetry and spectroscopy, aromaticity, aromatic reactivity, heterocyclic chemistry, chemistry of peptides and DNA. Prerequisite: CHEM 121.

CHEM 124. Organic Chemistry Laboratory. 3 Units.
This is a laboratory course that serves as a stepping stone toward independent research in organic chemistry. Through several 1-2 step syntheses, this course trains students on basic organic laboratory techniques on purification of products, including extraction, distillation, recrystallization, thin layer chromatography, and column chromatography, as well as characterization of product structures using IR, GC-MS, and NMR spectroscopy. This course reviews MS, IR, and 1H and 13C NMR spectroscopy knowledge from Chem 33 and 121 with an emphasis on the practical interpretation of spectra, so that students can become independent in using these techniques to identify the purity and structures of organic compounds.nPrerequisite: Chem 121. Corequisite: Chem 123.

CHEM 126. Synthesis Laboratory. 3 Units.
This is a laboratory course that will provide a true experience of what it is like to perform research in synthetic organic chemistry. Emphasis will be on proper reaction setup, reaction monitoring, and complete characterization of final products using chromatographic and spectroscopic methods. Students will be utilizing modern electronic notebooks to prepare for and document their experiments. Concludes with an individual synthesis project. Prerequisites: Chem 124.

CHEM 131. Instrumental Analysis Principles and Practice. 5 Units.
The core objectives of the course will focus upon introducing and providing hands-on practice with analytical separation, spectroscopic identification, and calibrated quantification with strong technical communication (for the Writing-in-the-Major requirement) emphasized throughout the course. Lectures will focus on theory, and laboratory activities will provide hands-on practice with the GC, LC, XPS, ICP, MS, and UV/Vis instruments. Data analysis will be emphasized throughout the course with Python being the primary tool for plotting and computations. Statistical measurements will be introduced to gauge the quality and validity of data. Lectures will be three times a week with a required four-hour laboratory section. The course will conclude with a student-developed project, focusing upon separation and quantification, and a poster presentation. The course should be completed prior to CHEM courses 174,176, or 184. Prerequisite: CHEM 33 or CHEM 100.

CHEM 141. The Chemical Principles of Life I. 4 Units.
This is the first course in a two-quarter sequence (Chem 141/143), which will examine biological science through the lens of chemistry. In this sequence students will gain a qualitative and quantitative understanding of the molecular logic of cellular processes, which include expression and transmission of the genetic code, enzyme kinetics, biosynthesis, energy storage and consumption, membrane transport, and signal transduction. Connections to foundational principles of chemistry will be made through structure-function analyses of biological molecules. Integrated lessons in structural, mechanistic, and physical chemistry will underscore how molecular science and molecular innovation have impacted biology and medicine. Prerequisites: CHEM 121, MATH 21 or equivalent.

CHEM 143. The Chemical Principles of Life II. 4 Units.
(Not offered in AY2020-21) This is the second course in a two-quarter sequence (Chem 141/143), which will continue the discussion of biological science through the lens of chemistry. In this sequence students will gain a qualitative and quantitative understanding of the molecular logic of cellular processes, which include expression and transmission of the genetic code, enzyme kinetics, biosynthesis, energy storage and consumption, membrane transport, and signal transduction. Connections to foundational principles of chemistry will be made through structure-function analyses of biological molecules. Integrated lessons in structural, mechanistic, and physical chemistry will underscore how molecular science and molecular innovation have impacted biology and medicine. Prerequisite: Chem 141.

CHEM 151. Inorganic Chemistry I. 4 Units.
Bonding, stereochemical, and symmetry properties of discrete inorganic molecules are covered along with their mechanisms of ligand and electron exchange. Density function calculations are extensively used in these analyses in computer and problem set exercises. Prerequisites: CHEM 33.

CHEM 153. Inorganic Chemistry II. 3 Units.
The theoretical aspects of inorganic chemistry. Group theory; many-electron atomic theory; molecular orbital theory emphasizing general concepts and group theory; ligand field theory; application of physical methods to predict the geometry, magnetism, and electronic spectra of transition metal complexes. Prerequisites: CHEM 151, 173.

CHEM 155. Advanced Inorganic Chemistry. 3 Units.
Chemical reactions of organotransition metal complexes and their role in homogeneous catalysis. Analogous patterns among reactions of transition metal complexes in lower oxidation states. Physical methods of structure determination. Prerequisite: one year of physical chemistry.
Same as: CHEM 255

CHEM 156. Single-Crystal X-ray Diffraction. 3 Units.
(Formerly 150) Practical X-ray crystallography for small molecule compounds, which will emphasize crystal growth, measurement strategies, structure solution and refinement, and report generation. Example structures will include absolute configuration of organic compounds (with the heaviest atom being oxygen), metal containing complexes, disordered small molecules and twinning. Students will learn how to get from a new compound to a single crystal, and then to a cif-file ready for publication submission. They will gain knowledge of the underlying theory and concepts for each step of structure determination.
Same as: CHEM 256

CHEM 171. Foundations of Physical Chemistry. 4 Units.
Quantum and statistical thermodynamics: obtaining quantum mechanical energy levels and connecting them to thermodynamic properties using statistical mechanics. Emphasis will be on quantum mechanics of ideal systems (e.g. particle in a box, particle in a ring, harmonic oscillator, hydrogen atom) and their connection to and uses in thermodynamics (laws of thermodynamics, properties of gases, chemical equilibria, thermal motion and energy barriers, and rates of chemical reactions). Homeworks and discussion sections will employ the Python programming language for hands-on experience with simulating chemical systems. Prerequisites: CHEM 33; PHYS 41; CS106A; either MATH 51 or CME 100.

CHEM 173. Physical Chemistry II. 3 Units.
Introduction to quantum chemistry: the basic principles of wave mechanics, the harmonic oscillator, the rigid rotator, infrared and microwave spectroscopy, the hydrogen atom, atomic structure, molecular structure, valence theory. Prerequisites: CHEM 171; either MATH 53 or PHYSICS 43; CME 102 and CME 104.

CHEM 174. Electrochemical Measurements Lab. 3 Units.
Introduction to modern electrochemical measurement in a hands-on, laboratory setting. Students assemble and use electrochemical cells including indicator, reference, working and counter electrodes, with macro, micro and ultramicro geometries, salt bridges, ion-selective membranes, electrometers, potentiostats, galvanostats, and stationary and rotated disk electrodes. The later portion of the course will involve a student-generated project to experimentally characterize some electrochemical system. Prerequisites: CHEM 131 (formerly 134) and CHEM 171, MATH 51, PHYSICS 44 or equivalent.
Same as: CHEM 274

CHEM 175. Physical Chemistry III. 3 Units.
Molecular theory of kinetics and statistical mechanics: transport and reactions in gases and liquids, ensembles and the Boltzmann distribution law, partition functions, molecular simulation, structure and dynamics of liquids. Diffusion and activation limited reactions, potential energy surfaces, collision theory and transition-state theory. Prerequisites: CHEM 171, CHEM 173.

CHEM 176. Spectroscopy Laboratory. 3 Units.
Use of spectroscopic instrumentation to obtain familiarity with important types of spectrometers and spectroscopic methods and to apply them to study molecular properties and time dependent processes. Methods include electronic ultraviolet/ visible absorption, fast fluorescence with time correlated single photon counting, Raman and fluorescence microscopy, Fourier transform infrared absorption, and nuclear magnetic resonance. Prerequisite: CHEM 173.

CHEM 181. Biochemistry I. 4 Units.
Structure and function of major classes of biomolecules, including proteins, carbohydrates and lipids. Mechanistic analysis of properties of proteins including catalysis, signal transduction and membrane transport. Students will also learn to critically analyze data from the primary biochemical literature. Satisfies Central Menu Area 1 for Bio majors. Prerequisites: Chem 121 (formerly 35).
Same as: CHEMENG 181, CHEMENG 281

CHEM 183. Biochemistry II. 3 Units.
Focus on metabolic biochemistry: the study of chemical reactions that provide the cell with the energy and raw materials necessary for life. Topics include glycolysis, gluconeogenesis, the citric acid cycle, oxidative phosphorylation, photosynthesis, the pentose phosphate pathway, and the metabolism of glycogen, fatty acids, amino acids, and nucleotides as well as the macromolecular machines that synthesize RNA, DNA, and proteins. Medical relevance is emphasized throughout. Satisfies Central Menu Area 1 for Bio majors. Prerequisite: CHEM 181 or CHEM 141 or CHEMENG 181/281.
Same as: CHEMENG 183, CHEMENG 283

CHEM 184. Biological Chemistry Laboratory. 3 Units.
Modern techniques in biological chemistry including protein purification, characterization of enzyme kinetics, heterologous expression of His-tagged fluorescent proteins, site-directed mutagenesis, and a course-based undergraduate research experience (CURE) module. Prerequisite: CHEM 181.

CHEM 185. Biophysical Chemistry. 3 Units.
Primary literature based seminar/discussion course covering classical and contemporary papers in biophysical chemistry. Topics include (among others): protein structure and stability, folding, single molecule fluorescence and force microscopy, simulations, ion channels, GPCRs, and ribosome structure/function. Course is restricted to undergraduates: required for majors on the Biological Chemistry track, but open to students from the regular track. Prerequisites: Chem 171, Chem 173 and Chem 181.

CHEM 190. Advanced Undergraduate Research. 1-5 Unit.
Limited to undergraduates who have completed Chem 121 (formerly 35) and/or Chem 134, or by special arrangement with a faculty member. May be repeated 8 times for a max of 27 units. Prerequisite: CHEM 121 (formerly 35) or 134. Corequisite: CHEM 300.

CHEM 193. Interdisciplinary Approaches to Human Health Research. 1 Unit.
For undergraduate students participating in the Stanford ChEM-H Undergraduate Scholars Program. This course will expose students to interdisciplinary research questions and approaches that span chemistry, engineering, biology, and medicine. Focus is on the development and practice of scientific reading, writing, and presentation skills intended to complement hands-on laboratory research. Students will read scientific articles, write research proposals, make posters, and give presentations.
Same as: BIO 193, BIOE 193, CHEMENG 193

CHEM 196. Creating and Leading New Ventures in Engineering and Science-based Industries. 3 Units.
Open to seniors and graduate students interested in the creation of new ventures and entrepreneurship in engineering and science intensive industries such as chemical, energy, materials, bioengineering, environmental, clean-tech, pharmaceuticals, medical, and biotechnology. Exploration of the dynamics, complexity, and challenges that define creating new ventures, particularly in industries that require long development times, large investments, integration across a wide range of technical and non-technical disciplines, and the creation and protection of intellectual property. Covers business basics, opportunity viability, creating start-ups, entrepreneurial leadership, and entrepreneurship as a career. Teaching methods include lectures, case studies, guest speakers, and individual and team projects.
Same as: CHEM 296, CHEMENG 196, CHEMENG 296

CHEM 200. Research and Special Advanced Work. 1-15 Unit.
Qualified graduate students undertake research or advanced lab work not covered by listed courses under the direction of a member of the teaching staff.

CHEM 211A. Research Progress in Chemistry. 1 Unit.
Required of all second year Ph.D. students. Students present their research progress and plans in brief written and oral summaries.

CHEM 211B. Chemistry Research Seminar Presentation. 1 Unit.
Required of all third year Ph.D. students. Students present their research project as a seminar.

CHEM 211C. Chemistry Research Proposal. 1 Unit.
Required of all fourth year Ph.D. students. Students formulate, write, and orally defend an original research proposal.

CHEM 221. Advanced Organic Chemistry I. 3 Units.
Physical Organic Chemistry. This course is focused on understanding the important physical principles in organic chemistry, including bonding and structural analysis; molecular interactions; thermodynamics; kinetics; methods to investigate reactive intermediates, reactivity, and elucidate reaction mechanism. Prerequisite: Chem 123 (formerly 131).

CHEM 223. Advanced Organic Chemistry II. 3 Units.
Physical Organic Chemistry. This course is focused on understanding the important physical principles in organic chemistry, including bonding and structural analysis; molecular interactions; thermodynamics; kinetics; methods to investigate reactive intermediates, reactivity, and elucidate reaction mechanism. Prerequisite: Chem 123 (formerly 131).

CHEM 225. Advanced Organic Chemistry III. 3 Units.
Chemistry is driven by one's understanding of structure and mechanism and ones ability to make molecules. This course is intended to address the universal mechanistic and structural foundations of organic chemistry with an emphasis on new synthetic methods, selectivity analysis, computer-based strategies for the design and synthesis of complex molecules, concepts for innovative problems solving and, importantly, how to put these skills together in the generation of impactful ideas and proposals directed at solving problems in science as required for a career in molecular science. Prerequisite: CHEM 223 or consent of instructor.

CHEM 232. Applications of NMR Spectroscopy. 3 Units.
(Formerly 235) The uses of NMR spectroscopy in chemical and biochemical sciences, emphasizing data acquisition for liquid samples and including selection, setup, and processing of standard and advanced experiments.

CHEM 251. Advanced Inorganic Chemistry. 3 Units.
(Formerly Chem 253) Electronic structure and physical properties of transition metal complexes. Ligand field and molecular orbital theories, magnetism and magnetic susceptibility, electron paramagnetic resonance including hyperfine interactions and zero field splitting and electronic absorption spectroscopy including vibrational interactions. Prerequisite: advanced undergrad-level inorganic course (equivalent to CHEM 153).

CHEM 253. Fundamentals of Inorganic Chemistry. 3 Units.
(Formerly Chem 251) Intended for first-year graduate students and advanced undergraduate students, as a review of how basic concepts in inorganic chemistry can be applied to materials of all dimensionalities. Specific topics will include: symmetry (group theory), bonding models (crystal field theory, valence bond theory, molecular orbital theory, and the Bloch theorem) and electronic structure, and properties/reactivity of molecules and extended solids. Prerequisite: introductory undergraduate-level inorganic course (equivalent to CHEM 151).

CHEM 255. Advanced Inorganic Chemistry. 3 Units.
Chemical reactions of organotransition metal complexes and their role in homogeneous catalysis. Analogous patterns among reactions of transition metal complexes in lower oxidation states. Physical methods of structure determination. Prerequisite: one year of physical chemistry.
Same as: CHEM 155

CHEM 256. Single-Crystal X-ray Diffraction. 3 Units.
(Formerly 150) Practical X-ray crystallography for small molecule compounds, which will emphasize crystal growth, measurement strategies, structure solution and refinement, and report generation. Example structures will include absolute configuration of organic compounds (with the heaviest atom being oxygen), metal containing complexes, disordered small molecules and twinning. Students will learn how to get from a new compound to a single crystal, and then to a cif-file ready for publication submission. They will gain knowledge of the underlying theory and concepts for each step of structure determination.
Same as: CHEM 156

CHEM 257. Bio-Inorganic Chemistry. 3 Units.
(Formerly Chem 297) Overview of metal sites in biology. Metalloproteins as elaborated inorganic complexes, their basic coordination chemistry and bonding, unique features of the protein ligand, and the physical methods used to study active sites. Active site structures are correlated with function (election transfer; dioxygen binding, activation and reduction to water). Prerequisites: Chem 153 and Chem 173, or equivalents.
Same as: BIOPHYS 297

CHEM 258C. Research Progress in Inorganic Chemistry. 1 Unit.
Required of all second-, third-, and fourth-year Ph.D. candidates in inorganic chemistry. Students present their research progress in written and oral forms (A); present a seminar in the literature of the field of research (B); and formulate, write, and orally defend a research proposal (C). Second-year students register for A; third-year students register for B; fourth-year students register for C.

CHEM 261. Computational Chemistry. 3 Units.
Introduction to computational chemistry methodology with a focus on interpretation of and applications to experimental research. Project-based and hands-on experience with molecular dynamics simulation, determining reaction pathways, Monte Carlo simulation and modeling, and machine learning for applications in chemistry. Prerequisite: knowledge of undergraduate level quantum mechanics and statistical mechanics at the levels of Chem 173 and Chem 175.

CHEM 271. Advanced Physical Chemistry. 3 Units.
The principles of quantum mechanics. General formulation, mathematical methods, and applications of quantum theory. Different representations of quantum theory, i. e., the Dirac, Schrödinger, matrix, and density matrix methods. Time independent exactly solvable problems and approximate methods including time independent perturbation theory and the variational method. Atomic energy calculations, angular momentum, and introduction to molecular structure methods. Time dependent methods. Time dependent perturbation theory applied to various problems such as absorption and emission of radiation. Time dependent density matrix formalism applied to coherent coupling of radiation fields to molecular systems, e. g., NMR and optical spectroscopy. Prerequisite: Chem. 175 or equivalent course.

CHEM 273. Advanced Physical Chemistry. 3 Units.
Statistical mechanics is a fundamental bridge that links microscopic world of quantum mechanics to macroscopic thermodynamic properties. We discuss the principles and methods of statistical mechanics from the ensemble point of view. Applications include statistical thermodynamics, quantum systems, heat capacities of gases and solids, chemical equilibrium, pair correlation functions in liquids, and phase transitions. Prerequisite: CHEM 271.

CHEM 274. Electrochemical Measurements Lab. 3 Units.
Introduction to modern electrochemical measurement in a hands-on, laboratory setting. Students assemble and use electrochemical cells including indicator, reference, working and counter electrodes, with macro, micro and ultramicro geometries, salt bridges, ion-selective membranes, electrometers, potentiostats, galvanostats, and stationary and rotated disk electrodes. The later portion of the course will involve a student-generated project to experimentally characterize some electrochemical system. Prerequisites: CHEM 131 (formerly 134) and CHEM 171, MATH 51, PHYSICS 44 or equivalent.
Same as: CHEM 174

CHEM 275. Advanced Physical Chemistry - Single Molecules and Light. 3 Units.
Covers optical single-molecule detection, spectroscopy, and imaging for detection of motional dynamics, super-resolution structure beyond the diffraction limit, and nanoscale interactions and orientations mostly in biological materials. May include an in-class laboratory component. Recommended: CHEM 271 or PHYSICS 230 and CHEM 273 or equivalent.

CHEM 277. Materials Chemistry and Physics. 3 Units.
(Not offered in AY2020-21) Topics: structures and symmetries and of solid state crystalline materials, chemical applications of group theory in solids, quantum mechanical electronic band structures of solids, phonons in solids, synthesis methods and characterization techniques for solids including nanostructured materials, selected applications of solid state materials and nanostructures. May be repeated for credit.

CHEM 279. Chemophysical analyses of costs to lower atmospheric concentrations of greenhouse gases. 3 Units.
Many methods have been proposed to reduce future concentration of CO2, CH4 and other greenhouse gases in the atmosphere from stricter emission regulations, to lower carbon energy sources, to more distribution of existing resources over space and time, to atmospheric capture and sequestration of gases already in the atmosphere. All methods would impose costs in some form. What can chemical and physical analyses tell us about the costs of different approaches? In this graduate-level seminar, students will read primary literature examining the chemical and physical challenges and limitations of various approaches and, by rigorous assessment of the theory and data available to date, will seek to estimate a credible range of future costs for each approach. Prerequisite: Previous study of thermodynamics, kinetics and quantum mechanics at the level of Chemistry 171 and 173.

CHEM 280. Single-Molecule Spectroscopy and Imaging. 3 Units.
Theoretical and experimental techniques necessary to achieve single-molecule sensitivity in laser spectroscopy: interaction of radiation with spectroscopic transitions; systematics of signals, noise, and signal-to-noise; modulation and imaging methods; and analysis of fluctuations; applications to modern problems in biophysics, cellular imaging, physical chemistry, single-photon sources, and materials science. Prerequisites: CHEM 271, previous or concurrent enrollment in CHEM 273.

CHEM 281. Therapeutic Science at the Chemistry - Biology Interface. 3 Units.
(Formerly Chem 227) Explores the design and enablement of new medicines that were born from a convergence of concepts and techniques from chemistry and biology. Topics include an overview of the drug development process, design of of small molecule medicines with various modes of action, drug metabolism and pharmacogenomics, biologic medicines including protein- and nucleic acid-based therapeutics, glycoscience and glycomimetic drugs, and cell-based medicines derived from synthetic biology. Prerequisite: undergraduate level organic chemistry and biochemistry as well as familiarity with concepts in cell and molecular biology.

CHEM 283. Synthesis and Analysis at the Chemistry-Biology Interface. 3 Units.
(Formerly 226) Focus on the combined use of organic chemistry and molecular biology to make, manipulate and measure biomacromolecules, with special focus on DNA and RNA. Synthetic and enzymatic methods for design and construction of oligonucleotides and nucleic acids; methods for bioconjugation and labeling; fluorescence tools; intracellular delivery strategies; selection and evolution methods; CRISPR mechanisms. Prerequisite: One year of undergraduate organic chemistry. Completion of a course in molecular biology is strongly recommended.

CHEM 285. Biophysical Chemistry. 3 Units.
Primary literature based seminar/discussion course covering classical and contemporary papers in biophysical chemistry. This is intended to provide an introduction to critical analysis of papers in the literature through intensive discussion and evaluation. Topics include (among others): protein structure and stability, folding, single molecule fluorescence and force microscopy, simulations, ion channels, GPCRs, and ribosome structure/function. Course is limited to 15 students and priority will be given to first year Chemistry graduate students.

CHEM 289. Concepts and Applications in Chemical Biology. 3 Units.
Current topics include chemical genetics, activity-based probes, inducible protein degradation, DNA/RNA chemistry and molecular evolution, protein labeling, carbohydrate engineering, fluorescent proteins and sensors, optochemical/optogenetic methods, mass spectrometry, and genome-editing technologies.

CHEM 291. Introduction to Nuclear Magnetic Resonance. 3 Units.
Introduction to quantum and classical descriptions of NMR; analysis of pulse sequences and nuclear spin coherences via density matrices and the product operator formalism; NMR spectrometer design; Fourier analysis of time-dependent observable magnetization; NMR relaxation in liquids and solids; NMR strategies for biological problem solving. Prerequisite: Chem 173.

CHEM 296. Creating and Leading New Ventures in Engineering and Science-based Industries. 3 Units.
Open to seniors and graduate students interested in the creation of new ventures and entrepreneurship in engineering and science intensive industries such as chemical, energy, materials, bioengineering, environmental, clean-tech, pharmaceuticals, medical, and biotechnology. Exploration of the dynamics, complexity, and challenges that define creating new ventures, particularly in industries that require long development times, large investments, integration across a wide range of technical and non-technical disciplines, and the creation and protection of intellectual property. Covers business basics, opportunity viability, creating start-ups, entrepreneurial leadership, and entrepreneurship as a career. Teaching methods include lectures, case studies, guest speakers, and individual and team projects.
Same as: CHEM 196, CHEMENG 196, CHEMENG 296

CHEM 299. Teaching of Chemistry. 1-3 Unit.
Required of all teaching assistants in Chemistry. Techniques of teaching chemistry by means of lectures and labs.

CHEM 300. Department Colloquium. 1 Unit.
Required of graduate students. May be repeated for credit.

CHEM 301. Research in Chemistry. 2 Units.
Required of graduate students who have passed the qualifying examination. Open to qualified graduate students with the consent of the major professor. Research seminars and directed reading deal with newly developing areas in chemistry and experimental techniques. May be repeated for credit. Search for adviser name on Axess.

CHEM 321. Topics in Stereochemistry. 3 Units.
Most areas of modern organic chemistry require of an understanding of stereochemical concepts. This course will discuss relevant developments in three central fields of stereochemistry, (1) conformational analysis, with particular emphasis in the influence of stereoelectronic interactions, (2) asymmetric synthesis, with specific applications in the stereoselective synthesis of a- and b-amino acids, and (3) sustainable chemistry and asymmetric organocatalysis. A solid foundation in organic chemistry is expected.

CHEM 329. Organic Chemistry Seminar. 1 Unit.
(Formerly 229) Required of graduate students majoring in organic chemistry. Students giving seminars register for CHEM 231.

CHEM 359. Inorganic Chemistry Seminar. 1 Unit.
(Formerly 259) Required of graduate students majoring in inorganic chemistry.

CHEM 371. Time-dependent statistical mechanics I. 3 Units.
First of a two-quarter sequence on the extension of the principles of statistical thermodynamics to systems away from equilibrium. We will explore the connection between the observable properties of such systems and the properties of their microscopic constituents. It will introduce students to many of the theoretical tools that researchers use to understand different kinds of time-dependent phenomena. The sequence will include coverage of the following topics: Phase space and the Liouville equation; equilibrium time correlation functions (TCFs); simple models of TCFs; linear response theory and transport coefficients; projection operators and generalized equations of motion; functional calculus and the Fokker-Planck, Langevin and generalized Langevin equations; chemical reaction dynamics and the Kramers equation; fluctuation theorems and non-equilibrium work relations; path integrals in the study of stochastic processes. Prerequisites: CHEM 175 or CHEM 273 or equivalent course in equilibrium statistical mechanics.

CHEM 373. Time-dependent statistical mechanics II. 3 Units.
Second of a two-quarter sequence surveying the statistical mechanical principles used in the study of time-dependent phenomena. It will continue to develop the themes introduced in CHEM 371, while illustrating their application to a variety of exactly solvable model systems, with examples drawn from the current research literature. Prerequisite: CHEM 371.

CHEM 379. Physical Chemistry Seminar. 1 Unit.
(Formerly 279) Required of graduate students majoring in physical chemistry. May be repeated for credit.

CHEM 390. Curricular Practical Training for Chemists. 1 Unit.
For Chemistry majors who need work experience as part of their program of study. Confer with Chem student services office for signup.

CHEM 459. Frontiers in Interdisciplinary Biosciences. 1 Unit.
Students register through their affiliated department; otherwise register for CHEMENG 459. For specialists and non-specialists. Sponsored by the Stanford BioX Program. Three seminars per quarter address scientific and technical themes related to interdisciplinary approaches in bioengineering, medicine, and the chemical, physical, and biological sciences. Leading investigators from Stanford and the world present breakthroughs and endeavors that cut across core disciplines. Pre-seminars introduce basic concepts and background for non-experts. Registered students attend all pre-seminars; others welcome. See http://biox.stanford.edu/courses/459.html. Recommended: basic mathematics, biology, chemistry, and physics.
Same as: BIO 459, BIOC 459, BIOE 459, CHEMENG 459, PSYCH 459

CHEM 802. TGR Dissertation. 0 Units.
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