DEPARTMENT OF CHEMISTRY

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The Department of Chemistry is the largest department representing the chemical sciences at Case Western Reserve University. It consists of 19 faculty members, 15 associated faculty, about 5 postdoctoral associates, approximately 60 graduate students, and over 100 undergraduate students majoring in chemistry. The department offers undergraduate and graduate degree programs leading to the Bachelor of Arts, Bachelor of Science, Master of Science, and Doctor of Philosophy.

The general focus of chemistry is on (1) understanding the basic properties of matter, (2) employing this knowledge in the design, synthesis, and characterization of materials with novel and useful properties, and (3) using chemical perspectives and tools to better understand biological systems. The various degree programs strive to develop all aspects of the student's chemical knowledge through a broad range of lecture and laboratory courses.

Chemical research is an integral part of the department's activities: over $3 million of federal, state, and private research support flows into the department each year. State-of-the-art research facilities are available to both graduate and undergraduate students. Undergraduates are encouraged to participate in research projects with individual faculty members in order to expand their hands-on training, problem-solving skills, and understanding of the scientific method as applied in chemical research. These research projects typically involve interchange and collaboration across all levels of experience and may also involve scientists from other departments and institutions.

Chemistry is often referred to as "the central science" because of its key role in interdisciplinary studies. Correspondingly, a degree in chemistry affords a broad range of employment opportunities. Chemists can direct their talents to specialized problems of applied research, or they can choose to delve into fundamental investigations. A degree in chemistry can cover the spectrum of chemical specialties, from biochemistry to interstellar chemistry. The degree also provides valuable preparation for other professions, such as medicine, dentistry, and law.

The American Chemical Society (http://www.acs.org), with more than 160,000 members, is the major professional society in the United States for practicing chemists. Both undergraduate and graduate students may join the society.

Facilities

The department's facilities for experimental and theoretical research are modern and extensive. They include diverse major instruments for use by faculty and students, as well as specialized equipment serving individual research groups. Shared instrumentation includes 400- and 500-MHz NMR spectrometers and ultrafast laser systems in both the Center for Chemical Dynamics and the newly established Ultrafast Laser Facility.

Other departmental instrumentation includes equipment for laser Raman spectroscopy, GC-MS and LC-MS/MS mass spectrometers, calorimeters, stopped-flow kinetics instrumentation, a circular dichroism spectrometer, an analytical ultracentrifuge, and equipment for electrochemical measurements. Access to very high-field NMR instrumentation is available on campus at the Cleveland Center for Membrane Structural Biology (CCMSB), which is equipped with numerous 500- to 900-MHz NMR spectrometers for solution and solid-state measurements. The chemistry department's computers are part of the campus-wide fiber optic communications network operated by Information Technology Services, and the entire University Circle area offers wireless access. In addition to the full complement of software, Internet, and library database services offered by the university, connections to off-site databases, such as SciFinder and Ohio Supercomputer Center, are available to departmental users.

The department uses some of the foremost equipment available in high-resolution nuclear magnetic resonance spectroscopy and in tunable laser spectroscopy. Work on various aspects of chemistry as studied by these techniques is recognized throughout the world.

Primary Faculty

Gregory P. Tochtrop, PhD
(Washington University Medical School)
Professor and Chair
Biochemistry, biophysical chemistry, chemical biology, medicinal chemistry, organic chemistry, bioorganic chemistry, synthesis

Clemens Burda, PhD
(University of Basel, Switzerland)
Chemical Professor
Photochemistry, materials, physical chemistry, nanochemistry, bio- and energy applications, biophysical and biomedical science and engineering, spectroscopy

Carlos E. Crespo-Hernández, PhD
(University of Puerto Rico)
Professor; Associate Dean for Research
Analytical chemistry, biophysical chemistry, energy, photochemistry, physical chemistry, chemical dynamics and kinetics, computational chemistry, environmental chemistry, time-resolved spectroscopy

Thomas G. Gray, PhD
(Harvard University)
Professor
Inorganic, Organometallic, Materials, and Computational Chemistry

Irene Lee, PhD
(Pennsylvania State University)
Professor
Biochemistry, medicinal chemistry, bioorganic chemistry

Fu-Sen Liang, PhD
(The Scripps Research Institute)
Associate Professor
Bioorganic chemistry

Drew A. Meyer, PhD
(Stanford University)
John Teagle Professorial Fellow in Chemistry; Senior Instructor
Physical chemistry, inorganic chemistry, X-ray spectroscopy, chemical education

Shane M. Parker, PhD
(Northwestern University)
Frank Hovorka Assistant Professor of Chemistry
Computational and theoretical chemistry

John D. Protasiewicz, PhD
(Cornell University)
Hurlbut Professor of Chemistry
Inorganic chemistry, materials and energy, organometallic chemistry, photochemistry, catalysis, computational chemistry, crystallography, electrochemistry, green chemistry, main group chemistry, molecular electronics, nanotechnology, OLEDs, optoelectronics, physical organic chemistry, polymers, solar energy, solid-state chemistry, spectroscopy, supramolecular chemistry, synthesis

Robert G. Salomon, PhD
(University of Wisconsin, Madison)
Charles Frederic Mabery Professor of Research in Chemistry
Biochemistry, chemical biology, medicinal chemistry, organic chemistry, bioorganic chemistry, cellular biology, molecular biology, natural products, pharmacology, synthesis

Anna C. Samia, PhD
(Georgia Institute of Technology)
Associate Professor
Analytical chemistry, inorganic chemistry, materials and energy, bioinorganic chemistry, functional nanomaterials, nanotheranostics

Geneviève Sauvé, PhD
(California Institute of Technology)
Professor
Materials and energy, organic chemistry, physical chemistry, functional polymers, nanoscale morphology, organic electronics, solar energy conversion, structure-property relationships

Daniel A. Scherson, PhD
(University of California, Davis)
Frank Hovorka Professor of Chemistry
Analytical chemistry, materials, physical chemistry, photochemistry, electrochemistry

Rekha R. Srinivasan, PhD
(Case Western Reserve University)
Senior Instructor
Analytical chemistry, biophysical chemistry, organic chemistry, chemical education

Blanton S. Tolbert, PhD
(University of Rochester)
Rudolph and Susan Rense Professor of Chemistry
Biochemistry, biophysical chemistry, structural biology

Michael G. Zagorski, PhD
(Case Western Reserve University)
Professor
Biochemistry, biophysical chemistry, chemical biology, organic chemistry, beer brewing, bioorganic chemistry, drug delivery, NMR, structural biology

Lecturers

Krista Cunningham, PhD
(The Ohio State University)
Full-time Lecturer
Organic chemistry, chemical education

Benjamin Sturtz, PhD
(Case Western Reserve University)
Full-time Lecturer
Inorganic Chemistry

Research Faculty

Mikhail D. Linetsky, PhD
(Academy of Science of Ukraine)
Research Professor
Biochemistry, chemical biology, protein chemistry, post-translational protein modification, proteomics

Secondary Faculty

Paul Carey, PhD
(University of Sussex, UK)
Professor, Department of Biochemistry
Biochemistry, biophysical chemistry, microscopy/imaging, spectroscopy

Chris Dealwis, PhD
Associate Professor, Department of Pharmacology
Biochemistry, biophysics, enzyme catalysis, pharmacology, proteins

Thomas Gerken, PhD
(Case Western Reserve University)
Professor, Division of Pediatric Pulmonology
Biochemistry, biophysical chemistry, chemical biology, glycosylation, protein chemistry, protein structure

Burcu Gurkan, PhD
(University of Notre Dame)
Assistant Professor, Chemical Engineering
Chemical Engineering

Thomas Kelley, PhD
(University of Notre Dame)
Associate Professor, Division of Pediatric Pulmonology
Biochemistry, medicinal chemistry, cellular biology, pharmacology

Lydia Kisley, PhD
(Rice University)
Assistant Professor, Department of Physics
Experimental biophysics, soft condensed matter physics, microscopy, interfacial/surface science, nanoscience, physical chemistry/chemical physics, signal processing, image analysis

Witold K. Surewicz, PhD
(University of Lodz, Poland)
Professor, Department of Physiology and Biophysics
Biochemistry, biophysical chemistry, neurochemistry, spectroscopy

Yanming Wang, PhD
(Federal Institute of Technology, Zürich, Switzerland)
Associate Professor, Department of Radiology
Organic synthesis, molecular probes for in vivo imaging

Gary E. Wnek, PhD
(University of Massachusetts, Amherst)
The Joseph F. Toot, Jr., Professor of Engineering Professor, Macromolecular Science & Engineering
Polymeric biomaterials for drug delivery and regenerative medicine; nano- and micro-fiber fabrication; bio-mimicking approaches for polymer flammability mitigation; polymer packaging systems design; polyelectrolyte gels and elastomers; physiologically-mimicking macromolecular constructs with attention to primitive motile and irritable systems

Lei Zhu, PhD
(University of Akron)
Associate Professor, Department of Macromolecular Science & Engineering
Polymer structure and morphology, polymers for energy storage, nanocomposites, polymers for drug delivery

Adjunct Faculty

Michael J. Kenney, PhD
(Iowa State University)
Adjunct Associate Professor
Analytical chemistry, physical chemistry, chemical education, computer programming, application development

Emily B. Pentzer, PhD
(Northwestern University)
Adjunct Associate Professor
Energy, Materials, Nanoscience, Organic Chemistry, Polymer Chemistry, Supramolecular Chemistry, Surface Chemistry, Sustainability & Green, Synthesis

M. Cather Simpson, PhD
(University of New Mexico)
Adjunct Associate Professor
Biophysical chemistry; spectroscopic studies of biologically significant processes

Rajesh Viswanathan, PhD
(Indiana University)
Adjunct Associate Professor
Chemical biology of natural products and their bioactive derivatives, chemo-enzymatic synthesis of alkaloid natural products and their derivatives, synthetic biology strategies for accessing novel chemical diversity in alkaloids, peptides and polyketides, development of medicinal chemistry platforms for discovery of anti-cancer, anti-virulent and anti-malarial lead compounds

Emeritus Faculty

Alfred B. Anderson, PhD
(Johns Hopkins University)
Emeritus Professor
Materials, physical chemistry, electrocatalysis, interfacial phenomena, catalysis, theoretical chemistry

Mary D. Barkley, PhD
(University of California, San Diego)
Emeritus Professor and M. Roger Clapp University Professor of Arts and Sciences
Analytical chemistry, biochemistry, biophysical chemistry, medicinal chemistry, photochemistry, physical chemistry, theoretical chemistry

Malcolm E. Kenney, PhD
(Cornell University)
Emeritus Professor and Hurlbut Professor of Chemistry
Biochemistry, inorganic chemistry, materials and energy, organometallic chemistry, bioinorganic chemistry, computational chemistry, drug delivery, dyes and pigments, medicinal chemistry, nanotechnology, organosilicon chemistry, photochemistry, photodynamic therapy, polymers

Barry Miller, PhD
(Massachusetts Institute of Technology)
Frank Hovorka Professor Emeritus of Chemistry
Physical chemistry, electrochemistry

Anthony J. Pearson, PhD
(University of Aston, Birmingham, England)
Rudolph and Susan Rense Professor Emeritus of Chemistry
Organic chemistry, organometallic chemistry, catalysis, natural products, synthesis

Terry Swift, PhD
Professor Emeritus of Chemistry
Analytical chemistry

Fred L. Urbach, PhD
(Michigan State University)
Professor Emeritus of Chemistry
Analytical chemistry, biochemistry, inorganic chemistry, bioinorganic chemistry, catalysis

Majors

The Department of Chemistry offers three curricula for undergraduate majors, leading to a Bachelor of Science (BS) degree in chemistry, Bachelor of Arts (BA) degree in chemistry, or Bachelor of Arts (BA) degree in chemical biology.

Bachelor of Science in Chemistry

The BS program in chemistry is designed for students who seek professional careers in the chemical sciences and is certified by the American Chemical Society. The BS curriculum provides a rigorous background in chemistry, yet offers considerable flexibility in the senior year in the choice of electives, allowing BS majors to pursue areas of chemistry of particular interest to them in greater depth. At least three units of research (CHEM 397 / CHEM 398) are required, and up to nine units of research may be credited toward the degree.

Total Units Required for Graduation: 120

Chemistry BS - Required Chemistry Courses

First Year	Units	
	Fall	Spring
Principles of Chemistry I (CHEM 105)	3	
Principles of Chemistry Laboratory (CHEM 113)	2	
Principles of Chemistry II (CHEM 106)		3
Year Total:	5	3

Second Year	Units	
	Fall	Spring
Quantitative Analysis Laboratory (CHEM 304)	2	
Foundations of Analytical Chemistry (CHEM 310)	3	
Organic Chemistry I (CHEM 323)	3	
Inorganic Chemistry I (CHEM 311)		3
Laboratory Methods in Organic Chemistry (CHEM 322)		3
Organic Chemistry II (CHEM 324)		3
Year Total:	8	9

Third Year	Units	
	Fall	Spring
Laboratory Methods in Inorganic Chemistry (CHEM 331)	3	
Physical Chemistry I (CHEM 335)	3	
Laboratory Methods in Physical Chemistry (CHEM 332)		3
Physical Chemistry II (CHEM 336)		3
Chemistry Elective (300-level, see text below)		3
Year Total:	6	9

Fourth Year	Units	
	Fall	Spring
Research Requirement:	3 - 6	
Undergraduate Research (CHEM 397) or Undergraduate Research/Senior Capstone Project (CHEM 398)		
Biochemistry Requirement (one of the following):	3 - 4	
Introductory Biochemistry I (CHEM 328) (spring, 3 units)		
Biochemistry II: Living Systems (CHEM 329) (fall, 3 units)		
Introduction to Biochemistry: From Molecules To Medical Science (BIOC 307) (4 units)		
Chemistry Elective (300-level, see text below)		3
Technical Electives (see text below)		6
Year Total:	6-10	9
Total Units in Sequence:		**55-59**

Chemistry BS - Additional Required Courses

MATH 121	Calculus for Science and Engineering I	4
MATH 122	Calculus for Science and Engineering II	4
or MATH 124	Calculus II	
MATH 223	Calculus for Science and Engineering III	3
or MATH 227	Calculus III	
One of the following:		3
MATH 224	Elementary Differential Equations	
MATH 228	Differential Equations	
STAT 312	Basic Statistics for Engineering and Science	
PHYS 121	General Physics I - Mechanics	4
or PHYS 123	Physics and Frontiers I - Mechanics	
PHYS 122	General Physics II - Electricity and Magnetism	4
or PHYS 124	Physics and Frontiers II - Electricity and Magnetism	
PHYS 221	Introduction to Modern Physics	3
Total Units		**25**

The chemistry elective may be any chemistry department course at the 300 level or above which is not part of the "core set," or selected courses with a strong chemistry content at the 300 level or above from other science departments. Only three units of CHEM 397 may be applied to a chemistry elective.

The technical electives may be chosen more widely from any of the physical sciences, math, or engineering courses. An additional six units of CHEM 397 may be taken as technical electives. Further additional units of CHEM 397 may be taken as free electives. Students may wish to group their electives into "tracks" of specialization in order to tailor their degree to a particular area of chemistry.

BS majors who plan to go on to graduate study may elect to take advanced courses in:

Inorganic Chemistry	
CHEM 412	Advanced Inorganic Chemistry I
Organic Chemistry	
CHEM 421	Advanced Organic Chemistry I
CHEM 422	Advanced Organic Chemistry II
CHEM 435	Synthetic Methods in Organic Chemistry
Physical Chemistry	
CHEM 406	Chemical Kinetics
CHEM 407	Chemical Thermodynamics
CHEM 446	Quantum Mechanics I

Students can also elect to take other graduate offerings. Interdisciplinary strengths can be achieved by selecting technical electives in biochemistry, biomedical engineering, chemical engineering, macromolecular science, and materials science as well as in biology; earth, environmental, and planetary sciences; mathematics, applied mathematics, and statistics; and physics.

Bachelor of Arts in Chemistry

The BA program in chemistry is intended for pre-professional students who plan careers in medicine, dentistry, veterinary medicine, pharmacy, or in other fields for which a baccalaureate degree in chemistry provides appropriate training. BA majors may supplement their required courses with additional chemistry courses or may utilize the curriculum’s flexibility to develop an interdisciplinary program of their choice. Many chemistry BA majors participate in undergraduate research within the Department of Chemistry (CHEM 397 / CHEM 398) or in other science departments, including those in the medical school.

Total Units Required for Graduation: 120

Chemistry BA - Required Chemistry Courses

First Year	Units	
	Fall	Spring
Principles of Chemistry I (CHEM 105)	3	
Principles of Chemistry Laboratory (CHEM 113)	2	
Principles of Chemistry II (CHEM 106)		3
Year Total:	5	3

Second Year	Units	
	Fall	Spring
Introductory Organic Chemistry I (CHEM 223) or Organic Chemistry I (CHEM 323)	3	
Introductory Organic Chemistry Laboratory I (CHEM 233) (see below*)	2	
Introductory Organic Chemistry II (CHEM 224) or Organic Chemistry II (CHEM 324)		3
Introductory Organic Chemistry Laboratory II (CHEM 234) (see below*) or Laboratory Methods in Organic Chemistry (CHEM 322)		2-3
Year Total:	5	5-6

Third Year	Units	
	Fall	Spring
Introductory Physical Chemistry I (CHEM 301) or Physical Chemistry I (CHEM 335)	3	
Quantitative Analysis Laboratory (CHEM 304)	2	
Foundations of Analytical Chemistry (CHEM 310)	3	
Introductory Physical Chemistry II (CHEM 302) or Physical Chemistry II (CHEM 336)		3
Introductory Physical Chemistry Laboratory (CHEM 305)		3
Year Total:	8	6

Fourth Year	Units
	Fall
Electives	
Year Total:	

Total Units in Sequence:	**32-33**

* CHEM 322 is offered in spring only, and may be substituted in place of *both* CHEM 233 and CHEM 234.

Chemistry BA - Additional Required Courses

PHYS 115	Introductory Physics I	4
or PHYS 121	General Physics I - Mechanics	
PHYS 116	Introductory Physics II	4
or PHYS 122	General Physics II - Electricity and Magnetism	
MATH 125	Math and Calculus Applications for Life, Managerial, and Social Sci I	4
or MATH 121	Calculus for Science and Engineering I	
MATH 126	Math and Calculus Applications for Life, Managerial, and Social Sci II	4
or MATH 122	Calculus for Science and Engineering II	
Total Units		16

Bachelor of Arts in Chemical Biology

The BA program in chemical biology is intended for pre-professional students who plan careers in medicine, dentistry, veterinary medicine, pharmacy, or for individuals seeking careers that utilize chemistry to solve problems affecting living systems. A key component of the major is the flexibility imparted by fewer required courses and the integration of six credit hours of technical electives. Many chemical biology BA majors participate in undergraduate research within the Department of Chemistry (CHEM 397 / CHEM 398) or in other science departments, including those in the medical school.

Total Units Required for Graduation: 120

Chemical Biology BA - Required Chemistry Courses

First Year	Units	
	Fall	Spring
Principles of Chemistry I (CHEM 105)	3	
Principles of Chemistry II (CHEM 106)		3
Principles of Chemistry Laboratory (CHEM 113)		2
Year Total:	3	5

Second Year	Units	
	Fall	Spring
Organic Chemistry I (CHEM 323) or CHEM 223 and CHEM 224	3-6	
Introductory Organic Chemistry Laboratory I (CHEM 233) (see below*) or Laboratory Methods in Organic Chemistry (CHEM 322)	2-3	
Biochemistry Laboratory (CHEM 306)		3
Introductory Biochemistry I (CHEM 328)		3
Year Total:	5-9	6

Third Year	Units
	Fall
Introductory Physical Chemistry I (CHEM 301) or Physical Chemistry I (CHEM 335)	3
Quantitative Analysis Laboratory (CHEM 304)	2
Foundations of Analytical Chemistry (CHEM 310)	3
Year Total:	8

Fourth Year	Units	
	Fall	Spring
Technical Electives (see text below)	6	
Undergraduate Research/Senior Capstone Project (CHEM 398)		3 - 6
Year Total:	6	3-6

Total Units in Sequence:	**36-43**

* CHEM 322 is offered in spring only, and may be substituted in place of *both* CHEM 233 and CHEM 234. Only one semester of organic chemistry

laboratory is required for our chemical biology BA program. However, some medical schools require two semesters of organic lab, so students should plan accordingly.

The technical electives may be chosen more widely from any of the physical sciences, math, or engineering courses. A maximum of six units of CHEM 397 may be taken as technical electives. Further additional units of CHEM 397 may be taken as free electives. Students may wish to group their electives into "tracks" of specialization in order to tailor their degree to a particular area of chemistry.

Chemical Biology BA - Additional Required Courses

BIOL 214	Genes, Evolution and Ecology	3
BIOL 214L	Genes, Evolution and Ecology Lab	1
BIOL 215	Cells and Proteins	3
BIOL 215L	Cells and Proteins Laboratory	1
PHYS 115	Introductory Physics I	4
or PHYS 121	General Physics I - Mechanics	
PHYS 116	Introductory Physics II	4
or PHYS 122	General Physics II - Electricity and Magnetism	
MATH 125	Math and Calculus Applications for Life, Managerial, and Social Sci I	4
or MATH 121	Calculus for Science and Engineering I	
MATH 126	Math and Calculus Applications for Life, Managerial, and Social Sci II	4
or MATH 122	Calculus for Science and Engineering II	
Total Units		**24**

Departmental Honors

Chemistry majors who have excellent academic records may participate in the Honors in Chemistry program. To graduate with honors in chemistry, a student must satisfy the following requirements:

1. A combined grade point average of 3.50 in chemistry, physics, and mathematics and an overall grade point average of 3.20
2. A minimum of six units of Undergraduate Research (CHEM 397), or chemical research done under another course number with departmental approval
3. A thesis approved by the department's undergraduate affairs committee based on the level of research, quality of the manuscript, and chemical content

Teacher Licensure in Chemistry

The chemistry department offers a special option for undergraduate students who wish to pursue a chemistry major and a career in teaching. The Adolescent to Young Adult (AYA) Teacher Education Program in Physical Sciences prepares CWRU students to receive an Ohio Teaching License for grades 7-12. Students declare a second major in education —which involves 36 hours in education and practicum requirements— and complete a planned sequence of chemistry content course work within the context of the BA chemistry major. The program is designed to offer several unique features not found in other programs and to place students in mentored teaching situations throughout their teacher preparation career. This small, rigorous program is designed to capitalize on the strengths of CWRU's chemistry department, its Teacher Education Program, and the relationships the university has built with area schools.

Chemistry Minor

Students may complete a minor in chemistry, defined as one year of freshman chemistry (including laboratory); two additional three-unit lecture courses; and two additional laboratory or approved courses. A recommended sequence would include:

Course List

CHEM 105	Principles of Chemistry I	3
CHEM 106	Principles of Chemistry II	3
CHEM 113	Principles of Chemistry Laboratory	2
CHEM 223	Introductory Organic Chemistry I	3
or CHEM 323	Organic Chemistry I	
CHEM 224	Introductory Organic Chemistry II	3
or CHEM 324	Organic Chemistry II	
CHEM 233	Introductory Organic Chemistry Laboratory I	2
CHEM 234	Introductory Organic Chemistry Laboratory II	2
Total Units		**18**

Other sequences may be followed after consultation with the Department of Chemistry.

Graduate Programs

Master of Science Programs

The MS degree in chemistry may be obtained by completing (1) a program that includes the preparation of a master's thesis, or (2) a program involving only course work. Both programs require a minimum of 30 units, of which up to six units may be for the master's thesis. Course work for the master's degree may be taken on a part-time basis, but thesis research can be undertaken only by full-time graduate students. Thus, only the master's degree without thesis can be earned entirely on a part-time basis.

The Science and Technology Entrepreneurship Program (STEP) is a three- or four-semester professional MS degree offered in chemistry as well as in biotechnology and physics. Students enter the Chemistry Entrepreneurship program with a bachelor's, master's, or doctoral degree in a chemistry-related field. The program consists of advanced courses in chemistry, business, and technology innovation and an entrepreneurial project with technical content in an existing company or new venture.

Doctor of Philosophy Program

The PhD degree in chemistry is granted to those students who have shown an extensive knowledge of advanced chemistry and the ability to do original research. The program usually requires four years of full-time study after the bachelor's degree. Besides advanced courses, the program consists of cumulative and oral examinations, seminars and colloquia, and an original research project. At least twelve months must be spent in residence on campus while fulfilling the PhD thesis research requirement.

Full-time graduate students who maintain satisfactory academic performance while pursuing the PhD degree in chemistry normally receive a stipend for teaching and/or research, which includes full tuition and a monthly amount sufficient to cover living expenses.

Research

The Department of Chemistry is noted for research programs in (1) chemical biology and (2) energy and materials. Projects range from synthetic studies of important bioactive substances, including antibiotics and DNA-binding substances, to detailed examination of the surface properties of materials used in batteries and electrolytic cells. Studies are being performed with molecules as simple as oxygen and as complicated as those which describe the active centers of enzymes or the protein core of insoluble aggregates that deposit in neurodegenerative disease. Efforts are being made to understand the basic chemical properties leading to reactive mediators generated from physiological lipids.

Other research is aimed at developing new drugs for photodynamic therapy and at understanding the mechanism of action of drugs for antiretroviral therapy. The influence of metal ions in modifying reactivity is a common interest of several members of the faculty, as is the development of organometallic compounds for materials and catalysis. Chemical surfaces are being studied, as are various applications of nanoparticles, from cells to the environment. Studies designed to characterize electrode-electrolyte interfaces, the electrochemical properties of new semiconductors, and single-cell microelectrodes are also ongoing. These efforts are complemented by theoretical studies on the interfacial structure and bonding of composite materials.

Case Western Reserve University ranks among the leading universities internationally in its strengths in electrochemistry and has brought these strengths together in the Yeager Center for Electrochemical Studies (YCES) (http://chemistry.case.edu/department/research/yces/). The interdisciplinary nature of electrochemistry involves the interaction of electrochemists in the chemistry and chemical engineering departments with metallurgists, surface physicists, inorganic and organic chemists, polymer membrane chemists, and electrical engineers. Such interactions, lacking on most campuses, are promoted at Case Western Reserve University through YCES. Graduate students in the chemistry department have the opportunity to specialize in electrochemistry in one of the most extensive course and research programs in the United States.

Colloquia and Seminars

The department sponsors a rich program of colloquia and seminars on recent advances in chemical research. Most notable among these is the Frontiers in Chemistry Lecture Series, in which scientists of international distinction lecture on major discoveries and developments in chemistry. In addition, a weekly colloquium series provides lectures by invited speakers in a variety of fields of chemical investigation. Both of these programs are addressed to an audience of faculty, graduate students, and other chemical scientists in the university and the Cleveland area, and are a vital means to broaden current knowledge. Numerous other seminars and meetings are held on a more specialized and informal level. Most individual research groups conduct weekly discussions to evaluate their progress.

Courses

CHEM 105. Principles of Chemistry I. 3 Units.
Atomic structure; thermochemistry; periodicity, bonding and molecular structure; intermolecular forces; properties of solids; liquids, gases and solutions. Recommended preparation: One year of high school chemistry.

CHEM 106. Principles of Chemistry II. 3 Units.
Thermodynamics, chemical equilibrium; acid/base chemistry; oxidation and reduction; kinetics; spectroscopy; introduction to nuclear, organic, inorganic, and polymer chemistry. Prereq: CHEM 105 or CHEM 111.

CHEM 111. Principles of Chemistry for Engineers. 4 Units.
A first course in university chemistry emphasizing chemistry of materials for engineering students. Atomic theory and quantitative relationships; gas laws and kinetic theory; solutions, acid-base properties and pH; thermodynamics and equilibrium; kinetics, catalysis, and mechanisms; molecular structure and bonding. Recommended preparation: One year of high school chemistry.

CHEM 113. Principles of Chemistry Laboratory. 2 Units.
A one semester laboratory based on quantitative chemical measurements. Experiments include analysis, synthesis and characterization, thermochemistry and chemical kinetics. Computer analysis of data is a key part of all experiments. Prereq or Coreq: CHEM 105 or CHEM 106 or CHEM 111 or ENGR 145.

CHEM 119. Concepts for a Molecular View of Biology I. 3 Units.
The first semester of a two-course sequence in elementary inorganic, organic, and biochemistry, intended for nursing students or non-majors. Topics include: atomic theory, the periodic table, chemical bonds, molecular geometry, ideal gas laws, equilibrium and reaction rates, acids and bases, nuclear chemistry, and nomenclature and reactions of organic compounds (including alkyl, aryl, alcohol, carbonyl, and amino compounds). Problems involving numeric computation are emphasized. This course is not open to students with credit for CHEM 105 or CHEM 111.

CHEM 121. Concepts for a Molecular View of Biology II. 3 Units.
The second course of a two-semester sequence in elementary inorganic, organic, and biochemistry, intended for nursing students or non-majors. Topics include: carbohydrates, lipids, proteins, enzyme kinetics, metabolic pathways and bioenergetics, DNA and RNA, methods of molecular biology, and nutrition. Applications to human physiology and medicine emphasized. This course is not open to students with credit for CHEM 223 or CHEM 323. Prereq: CHEM 119.

CHEM 223. Introductory Organic Chemistry I. 3 Units.
Introductory course for science majors and engineering students. Develops themes of structure and bonding along with elementary reaction mechanisms. Includes treatment of hydrocarbons, alkyl halides, alcohols, and ethers as well as an introduction to spectroscopy. Prereq: CHEM 106 or ENGR 145.

CHEM 224. Introductory Organic Chemistry II. 3 Units.
Continues and extends themes of structure and bonding from CHEM 223 and continues spectroscopy and more complex reaction mechanisms. Includes treatment of aromatic rings, carbonyl compounds, amines, and selected special topics. Prereq: CHEM 223 or CHEM 323.

CHEM 233. Introductory Organic Chemistry Laboratory I. 2 Units.
An introductory organic laboratory course emphasizing microscale operations. Synthesis and purification of organic compounds, isolation of natural products, and systematic identification of organic compounds by physical and chemical methods. Prereq: (CHEM 106 or ENGR 145) and CHEM 113. Prereq or Coreq: CHEM 223 or CHEM 323.

CHEM 234. Introductory Organic Chemistry Laboratory II. 2 Units.
A continuation of CHEM 233, involving multi-step organic synthesis, peptide synthesis, product purification and analysis using sophisticated analytical techniques such as chromatography and magnetic resonance spectroscopy. Prereq: CHEM 233. Prereq or Coreq: CHEM 224

CHEM 290. Chemical Laboratory Methods for Engineers. 3 Units.
Techniques of chemical synthesis, analysis, and characterization. Uses students' backgrounds in general and organic chemistry, but requires no background in chemical laboratory operations. Prereq or Coreq: CHEM 223 or CHEM 323.

CHEM 301. Introductory Physical Chemistry I. 3 Units.
First of a two-semester sequence covering principles and applications of physical chemistry, intended for chemistry and engineering majors and other students having primary interests in biochemical, biological or life-science areas. States and properties of matter. Thermodynamics and its application to chemical and biochemical systems. Chemical equilibrium. Electrochemistry. Recommended preparation: One year each of undergraduate physics and calculus, preferably including partial derivatives. Prereq: CHEM 106 or ENGR 145.

CHEM 302. Introductory Physical Chemistry II. 3 Units.
Continuation of CHEM 301. Chemical kinetics and catalysis. Introductory quantum chemistry. Spectroscopy. Statistical thermodynamics. Prereq: CHEM 301 or CHEM 335.

CHEM 304. Quantitative Analysis Laboratory. 2 Units.
A one-semester laboratory course providing practical experience in the analytical process. Focus is on statistical error analysis of measurements, method validation and instrument calibration, and reporting. Basic laboratory skills are developed and evaluated based on accuracy and precision of measurements. Experiments using titration, spectroscopy, electrochemistry, liquid and gas chromatography, and mass spectrometry are conducted. Prereq: (CHEM 106 or ENGR 145) and CHEM 113. Coreq: CHEM 310.

CHEM 305. Introductory Physical Chemistry Laboratory. 3 Units.
A one-semester laboratory course focusing on the principles and quantitative characterization of chemical and biochemical systems. Experiments include chemical equilibrium kinetics, electrochemistry, spectroscopy and the use of computers for the statistical analysis of experimental data. Seminar discussions and disciplinary writing of results. Counts as SAGES Departmental Seminar. Prereq: CHEM 301 and CHEM 304 or CHEM 335. Or Prereq or Coreq: CHEM 302 or CHEM 336.

CHEM 306. Biochemistry Laboratory. 3 Units.
A one semester laboratory and lecture course developed to introduce students to a variety of chemical biology laboratory themes including buffering, identification of amino acids, immunoassay, ligand binding, cellular fractionation, enzyme isolation and purification, proteomics, and enzyme kinetics. Techniques include titration, various forms of chromatography, colorimetric assays, electrophoresis, high performance liquid chromatography and liquid chromatography coupled with tandem mass spectrometry. Recommended preparation: CHEM 328/CHEM 428. Counts as SAGES Departmental Seminar. Prereq: CHEM 233.

CHEM 310. Foundations of Analytical Chemistry. 3 Units.
A one-semester lecture covering classical and modern aspects of the analytical process; analysis requirements, method selection including capabilities and limitations, sampling and sample processing, measurement data statistics for evaluation of precision and accuracy, method validation, and reporting. Fundamental concepts in equilibrium thermodynamics are covered in the context of chemical analysis. Methods based on titration, spectroscopy, electrochemistry, chromatography, and mass spectrometry are emphasized. Prereq: CHEM 106 and CHEM 113. Coreq: CHEM 304.

CHEM 311. Inorganic Chemistry I. 3 Units.
Fundamentals of inorganic chemistry. Topics include molecular structure, molecular shape and symmetry, structure of solids, d-metal complexes, oxidation and reduction, and acids and bases. Prereq or Coreq: CHEM 224 or CHEM 324.

CHEM 314. Innovation and French Science: Past, Present, and Future. 3 Units.
The French scientific enterprise over the past 250 years has been buffeted by politics, war, civil unrest, and economic and societal changes. This study abroad course examines the evolution of science in France in light of these influences, how women have play an outsized role relative to the U.S., and the centrality of the French to humanity's scientific endeavor over the centuries. Students will visit many important scientific venues, both historical and modern, around Paris and elsewhere in the country. Readings from a variety of sources -- scientific, literary, historical -- and informal meetings with French scientists, engineers, and students will provide a comprehensive portrait of French science and scientific history from a variety of perspectives. The course will be conducted in English, although there is ample opportunity to interact in French if the student desires. The course meets the CAS Global & Cultural Diversity Requirement and may meet breadth requirements in certain programs. Not available for credit to students who have completed FRCH 328/428, PHYS 333, WGST 333, or WLIT 353/453. Offered as CHEM 314, HSTY 314, PHYS 314, and WGST 314. Counts for CAS Global & Cultural Diversity Requirement.

CHEM 316. Frontiers of Inorganic Chemistry. 3 Units.
This course deals with five topics in inorganic chemistry of current interest. The topics are: ways in which inorganic chemistry can increase the quality of the environment, methods by which inorganic chemistry can lead to sustainable processes in a developed industrial society, advances in bioinorganic and medicinal inorganic chemistry of clinical importance, modern inorganic materials with unusual and valuable property sets, and representative industrial inorganic research and production processes. It is to be team taught. Offered as CHEM 316 and CHEM 416.

CHEM 322. Laboratory Methods in Organic Chemistry. 3 Units.
Experimental approach to the synthesis, purification and characterization of organic compounds. Nuclear magnetic resonance (NMR) and infrared (IR) spectroscopies; chromatographic techniques. Prereq: CHEM 304 and CHEM 223 or CHEM 323. Prereq or Coreq: CHEM 224 or CHEM 324.

CHEM 323. Organic Chemistry I. 3 Units.
Relationships between molecular structure and chemical reactivity and development of sophisticated problem-solving skills in the context of organic reaction mechanisms and multi-step synthesis. Homolytic and heterolytic substitution, elimination, oxidation and reduction reactions; topics in stereochemistry and spectroscopy. Recommended for chemistry, biochemistry, and related majors. Prereq: CHEM 106 or ENGR 145.

CHEM 324. Organic Chemistry II. 3 Units.
Continuation of CHEM 323. Introduces the chemistry of carbonyl, aromatic and amino functional groups, and develops the concepts of conjugation and resonance, molecular orbital theory and pericyclic reactions. Prereq: CHEM 223 or CHEM 323.

CHEM 325. Physical Methods for Determining Organic Structure. 3 Units.
Structure determination of organic compounds using mass spectrometry and modern instrumental techniques such as infrared, ultraviolet, visible, and nuclear magnetic resonance spectroscopy. Recommended preparation: Two semesters of undergraduate organic chemistry. Offered as CHEM 325 and CHEM 425.

CHEM 328. Introductory Biochemistry I. 3 Units.
A survey of biochemistry with a strong emphasis on the chemical logic underlying the structure, function, and evolution of biomolecules. Amino acids and protein structure, purification, and analysis. DNA, RNA, genes, and genomes. DNA replication, repair, and recombination. RNA synthesis and processing. Protein synthesis and turnover, control of gene expression. Hemoglobin. Drug development. Enzyme kinetics, catalytic and regulatory strategies. Carbohydrates. Offered as CHEM 328 and CHEM 428. Prereq: CHEM 224 or CHEM 323.

CHEM 329. Biochemistry II: Living Systems. 3 Units.
A survey of biochemical systems exploring their molecular circuitry and architecture. Lipids, cell membranes, channels and pumps. Signal transduction and receptors. Glycolysis, gluconeogenesis, citric acid cycle, and glycogen metabolism. Redox processes, electron transport, and photosynthesis. Fatty acid and amino acid biosynthesis and degradation. Nucleotide, lipid, and steroid biosynthesis. Sensory and immune systems. Molecular motors. Offered as CHEM 329 and CHEM 429. Prereq: CHEM 328.

CHEM 331. Laboratory Methods in Inorganic Chemistry. 3 Units.
Synthesis, separation techniques, physical properties, and analysis. Advanced techniques of chemical synthesis, leading the student to the preparation of interesting inorganic and organometallic compounds. Offered as: CHEM 331 and CHEM 431. Prereq: CHEM 322.

CHEM 332. Laboratory Methods in Physical Chemistry. 3 Units.
Modern techniques of physicochemical measurement, including, kinetics, spectroscopy, and electrochemistry and the use of statistical methods for the analysis of experimental data. Seminar discussions and disciplinary writing of results. Counts as SAGES Departmental Seminar. Prereq: CHEM 304. Prereq or Coreq: CHEM 336.

CHEM 333. Medicinal Chemistry and Drug Development. 3 Units.
This course provides an overview on how principles in chemistry and biology are integrated to facilitate drug development. Primary emphasis will be placed on the development of organic molecules as drugs and metabolic enzymes as drug targets. Subjects pertinent to the introduction of medicinal chemistry, evaluation of drug efficacies in vitro and in vivo, and drug metabolism will be covered. Offered as CHEM 333 and CHEM 433. Prereq: CHEM 223 or CHEM 323 and BIOL 215. Coreq: CHEM 224 or CHEM 324.

CHEM 335. Physical Chemistry I. 3 Units.
First of a two-semester sequence of physical chemistry for chemistry majors and others with career goals in the physical sciences or engineering. Thermodynamics and its application to chemical systems: First Law, Heat, Work, internal energy, State functions, Thermochemistry, Entropy, 2nd and 3rd law of thermodynamics, Chemical equilibrium, Real Gases, Phase diagrams, ideal and real solutions, Electrolyte solutions, and Electrochemical cells, batteries and fuel cells. Introduction to chemical kinetics. This class is taught using the flipped classroom strategy, where students are expected to learn the basic concepts before class by reading relevant notes and textbook sections, as well as watching videos and answering pre-class questions. In class, students work on exercises and solving problems. Students have ample opportunities to clarify concepts, ask questions, and learn from both peers (in group settings) and the teacher. Recommended preparation: One year each of undergraduate physics and calculus, including partial derivatives. Prereq: CHEM 106 or ENGR 145.

CHEM 336. Physical Chemistry II. 3 Units.
Continuation of CHEM 335. Reaction kinetics and catalysis. Reaction dynamics. Chemical quantum mechanics. Statistical mechanics and thermodynamics. Spectroscopy. Prereq: CHEM 335 or Chemical Engineering Major with at least Junior standing.

CHEM 340. Solar Energy Conversion. 3 Units.
This is a multidisciplinary course from a chemist's point of view. This course teaches the background necessary to read and understand the scientific literature on solar energy conversion, and includes some basic device physics, materials chemistry and chemistry. Topics provide an overview of the field and includes: Global energy perspective, principles of photovoltaics, crystalline solar cells, thin-film solar cells, dye-sensitized solar cells, organic solar cells (with emphasis on polymer-based solar cells), photoelectrochemical cells and artificial photosynthesis for fuel production, and semiconductor nanostructures and quantum dots for solar energy conversion. The course includes three laboratories and a demo using state-of-the-art equipment, as well as presentations of recent research articles by the graduate students. It is recommended that students have experience with thermodynamics. The following CWRU courses would meet this expectation: CHEM 301, CHEM 335, ENGR 225 or PHYS 313. Offered as CHEM 340 and CHEM 440. Prereq: CHEM 106 or ENGR 145.

CHEM 341. Functional Nanomaterials. 3 Units.
This course is designed to introduce important concepts on the fundamental physical and chemical properties of technologically important nanometer scale materials. The course will cover an overview of the scientific principles pertaining to new properties at the nanoscale; synthesis and characterization tools; and existing and emerging applications of nanomaterials. It will center on current research developments on major classes of functional nanomaterials, including plasmonic nanoparticles, quantum dots, nanomagnets, carbon nanotubes, nanocatalysts and hybrid inorganic/organic nanostructures. In addition an emphasis will be placed on understanding the broader societal, economical and environmental impact of the scientific and technological advances brought forward by nanotechnology. Offered as CHEM 341 and CHEM 441.

CHEM 342. Computational Chemistry. 3 Units.
An introduction to computational methods in electronic structure. Molecular mechanics, semiempirical molecular orbital calculations, ab initio, post Hartree-Fock, density-functional theories, and hybrid approaches will be addressed. Continuum solvation calculations will be considered, time permitting. Offered as CHEM 342 and CHEM 442. Prereq: CHEM 223 or CHEM 323.

CHEM 344. The Chemistry and Physics of Energy Storage. 3 Units.
This course will cover both scientific and economic aspects of the operation of energy storage devices currently being considered for both small and large scale applications ranging from portable electronics to the electrical grid. These devices include pumped hydro, flywheel, compressed air, batteries, supercapacitors, thermal conversion, regenerative fuel cells and redox flow cells. Not to be included in this course are energy conversion devices such as photovoltaics and windmills. This course would be of interest to both undergraduate and graduate students with interest in the general area of energy management and will cover the physics and chemistry principles associated with the various modes of storage. Students either individually or in small groups will be expected to prepare a written document at the end of the course that describes and summarizes each mode of storage, including a discussion of all aspects of the technology such as costs of installation and operation, environmental impact, and economic projections. As part of this exercise students will become familiar with the extraordinary resources offered by our library. Offered as CHEM 344 and CHEM 444. Prereq: CHEM 106.

CHEM 348. Chemistry Fermentation Brewing: To Discern the Molecular Basis of Fermentation and Beer Brewing. 3 Units.
This course includes in-depth discussions of the chemistry and procedures underlying either an aspect of the brewing process or a style of beer in order to discern the molecular basis of fermentation and beer brewing. The biochemistry of yeast fermentation and hops, as well as mashing, lautering, boiling, conditioning, filtering, and packaging will be discussed. There is no lab component (such as brewing beer), although field trips to pubs including the Jolly-Scholar pub (located on campus) will be part of the course, as well as invited speakers who have set up local microbreweries. Each student will be expected to have basic background knowledge of chemistry, such as material taught in standard first year General Chemistry courses. Offered as CHEM 348 and CHEM 448. Prereq: CHEM 106 or ENGR 145.

CHEM 350. Modern Molecular Spectroscopy: Study of the Interactions Between Light and Matter. 3 Units.
This course is aimed to provide a modern treatment of molecular spectroscopy for physical chemists and for other related areas of interest. At the same time, it will attempt to serve the more generally interested science and engineering student to learn about the many interactions that light undergoes with matter. Offered as CHEM 350 and CHEM 450. Prereq: CHEM 302 or CHEM 310 or CHEM 336.

CHEM 395. Chemistry Colloquium Series. 1 Unit.
Course content provided by Thursday chemistry department colloquia (or Frontiers in Chemistry lectures). Discussion sessions review previous lectures and lay foundation for forthcoming lectures.

CHEM 397. Undergraduate Research. 1 - 6 Units.
Independent research project within a research group in the chemistry department or, by petition, within a research group in another Case department. Arrangements should be made with the faculty member selected. Open to all chemistry majors and other qualified students; required for Honors in Chemistry. A written report is required each semester.

CHEM 398. Undergraduate Research/Senior Capstone Project. 3 - 6 Units.
Independent research project within a research group in the chemistry department or, by petition, within a research group in another Case department. Arrangements should be made by consultation with the faculty member selected and the Senior Capstone Committee of the chemistry department. Open to all chemistry majors and other qualified students. Satisfies the research requirement for Honors in Chemistry. A written report and public oral presentations are required. Counts as SAGES Senior Capstone.

CHEM 406. Chemical Kinetics. 3 Units.
Theory and characterization of chemical rate processes. Recommended preparation: Two semesters of undergraduate physical chemistry.

CHEM 407. Chemical Thermodynamics. 3 Units.
Thermodynamics and statistical thermodynamics and their application to chemical problems. Recommended preparation: Two semesters of undergraduate physical chemistry.

CHEM 412. Advanced Inorganic Chemistry I. 3 Units.
Chemistry of inorganic systems. Spectroscopy, magnetism, and stereochemistry of transition metal compounds. Recommended preparation: One semester of undergraduate inorganic chemistry and two semesters of undergraduate physical chemistry.

CHEM 414. Organometallic Reactions and Structures. 3 Units.
Bonding, structure, and mechanistic aspects of organometallic chemistry and the relevance of organometallic species to chemical catalysis. Recommended preparation: One semester of undergraduate inorganic chemistry.

CHEM 416. Frontiers of Inorganic Chemistry. 3 Units.
This course deals with five topics in inorganic chemistry of current interest. The topics are: ways in which inorganic chemistry can increase the quality of the environment, methods by which inorganic chemistry can lead to sustainable processes in a developed industrial society, advances in bioinorganic and medicinal inorganic chemistry of clinical importance, modern inorganic materials with unusual and valuable property sets, and representative industrial inorganic research and production processes. It is to be team taught. Offered as CHEM 316 and CHEM 416.

CHEM 421. Advanced Organic Chemistry I. 3 Units.
Structure, bonding, and molecular orbital theory. Stereochemistry and conformational analysis. Reaction mechanisms. Aromaticity and aromatic substitution. Pericyclic reactions, orbital symmetry conservation, and free radical chemistry. Recommended preparation: Two semesters of undergraduate organic chemistry.

CHEM 422. Advanced Organic Chemistry II. 3 Units.
Carbocations and carbanions. Nucleophilic and electrophilic aliphatic substitutions. Heterolytic addition and elimination reactions. Carbonyl reactions. Acyl transfer chemistry. Oxidations, reductions, and rearrangements. Prereq: CHEM 421.

CHEM 425. Physical Methods for Determining Organic Structure. 3 Units.
Structure determination of organic compounds using mass spectrometry and modern instrumental techniques such as infrared, ultraviolet, visible, and nuclear magnetic resonance spectroscopy. Recommended preparation: Two semesters of undergraduate organic chemistry. Offered as CHEM 325 and CHEM 425.

CHEM 428. Introductory Biochemistry I. 3 Units.
A survey of biochemistry with a strong emphasis on the chemical logic underlying the structure, function, and evolution of biomolecules. Amino acids and protein structure, purification, and analysis. DNA, RNA, genes, and genomes. DNA replication, repair, and recombination. RNA synthesis and processing. Protein synthesis and turnover, control of gene expression. Hemoglobin. Drug development. Enzyme kinetics, catalytic and regulatory strategies. Carbohydrates. Offered as CHEM 328 and CHEM 428.

CHEM 429. Biochemistry II: Living Systems. 3 Units.
A survey of biochemical systems exploring their molecular circuitry and architecture. Lipids, cell membranes, channels and pumps. Signal transduction and receptors. Glycolysis, gluconeogenesis, citric acid cycle, and glycogen metabolism. Redox processes, electron transport, and photosynthesis. Fatty acid and amino acid biosynthesis and degradation. Nucleotide, lipid, and steroid biosynthesis. Sensory and immune systems. Molecular motors. Offered as CHEM 329 and CHEM 429.

CHEM 431. Laboratory Methods in Inorganic Chemistry. 3 Units.
Synthesis, separation techniques, physical properties, and analysis. Advanced techniques of chemical synthesis, leading the student to the preparation of interesting inorganic and organometallic compounds. Offered as: CHEM 331 and CHEM 431. Prereq: CHEM 322

CHEM 433. Medicinal Chemistry and Drug Development. 3 Units.
This course provides an overview on how principles in chemistry and biology are integrated to facilitate drug development. Primary emphasis will be placed on the development of organic molecules as drugs and metabolic enzymes as drug targets. Subjects pertinent to the introduction of medicinal chemistry, evaluation of drug efficacies in vitro and in vivo, and drug metabolism will be covered. Offered as CHEM 333 and CHEM 433.

CHEM 435. Synthetic Methods in Organic Chemistry. 3 Units.
Systematic consideration of reactions involving functional group transformations and carbon-carbon bond formations used in modern organic synthesis. Recommended preparation: Two semesters of undergraduate organic chemistry.

CHEM 436. Complex Molecular Synthesis. 3 Units.
An advanced organic chemistry course providing students with an in-depth examination of the art of total synthesis drawing from both classical and recent examples. Recommended preparation: Two semesters of undergraduate organic chemistry.

CHEM 438. Bioorganic and Environmental Photochemistry. 3 Units.
This discusses the fundamental principles of molecular and supramolecular photochemistry. In particular, the fundamental paradigms of light absorption by molecules and the photochemical and photophysical mechanisms by which molecules dispose of the excess energy after light absorption will be described. The goal is to develop paradigms for understanding experimental and theoretical aspects of molecular photophysics relevant to bioorganic, supramolecular, and environmental photochemistry, as well as to other light-induced processes such as photosynthesis, photocatalysis, and photovoltaics. The paradigms for determining photochemical mechanisms, the theory of the fundamental photochemical primary processes, and examples of important photochemical primary processes will be reviewed. Selected experimental techniques and theoretical methods used to probe the dynamics of electronic excited states in molecules and their photoreactivity will be presented. Advanced photochemical applications for understanding the electronic relaxation pathways and photochemistry of selected families of bioorganic molecules and environmental pollutants in natural waters will be discussed. Recommended Preparation: Chemical Kinetics (CHEM 406 or equivalent) and Elementary Differential Equations (MATH 224 or equivalent). Prereq: CHEM 336 and MATH 124.

CHEM 440. Solar Energy Conversion. 3 Units.
This is a multidisciplinary course from a chemist's point of view. This course teaches the background necessary to read and understand the scientific literature on solar energy conversion, and includes some basic device physics, materials chemistry and chemistry. Topics provide an overview of the field and includes: Global energy perspective, principles of photovoltaics, crystalline solar cells, thin-film solar cells, dye-sensitized solar cells, organic solar cells (with emphasis on polymer-based solar cells), photoelectrochemical cells and artificial photosynthesis for fuel production, and semiconductor nanostructures and quantum dots for solar energy conversion. The course includes three laboratories and a demo using state-of-the-art equipment, as well as presentations of recent research articles by the graduate students. It is recommended that students have experience with thermodynamics. The following CWRU courses would meet this expectation: CHEM 301, CHEM 335, ENGR 225 or PHYS 313. Offered as CHEM 340 and CHEM 440.

CHEM 441. Functional Nanomaterials. 3 Units.
This course is designed to introduce important concepts on the fundamental physical and chemical properties of technologically important nanometer scale materials. The course will cover an overview of the scientific principles pertaining to new properties at the nanoscale; synthesis and characterization tools; and existing and emerging applications of nanomaterials. It will center on current research developments on major classes of functional nanomaterials, including plasmonic nanoparticles, quantum dots, nanomagnets, carbon nanotubes, nanocatalysts and hybrid inorganic/organic nanostructures. In addition an emphasis will be placed on understanding the broader societal, economical and environmental impact of the scientific and technological advances brought forward by nanotechnology. Offered as CHEM 341 and CHEM 441.

CHEM 442. Computational Chemistry. 3 Units.
An introduction to computational methods in electronic structure. Molecular mechanics, semiempirical molecular orbital calculations, ab initio, post Hartree-Fock, density-functional theories, and hybrid approaches will be addressed. Continuum solvation calculations will be considered, time permitting. Offered as CHEM 342 and CHEM 442. Prereq: CHEM 223 or CHEM 323.

CHEM 444. The Chemistry and Physics of Energy Storage. 3 Units.
This course will cover both scientific and economic aspects of the operation of energy storage devices currently being considered for both small and large scale applications ranging from portable electronics to the electrical grid. These devices include pumped hydro, flywheel, compressed air, batteries, supercapacitors, thermal conversion, regenerative fuel cells and redox flow cells. Not to be included in this course are energy conversion devices such as photovoltaics and windmills. This course would be of interest to both undergraduate and graduate students with interest in the general area of energy management and will cover the physics and chemistry principles associated with the various modes of storage. Students either individually or in small groups will be expected to prepare a written document at the end of the course that describes and summarizes each mode of storage, including a discussion of all aspects of the technology such as costs of installation and operation, environmental impact, and economic projections. As part of this exercise students will become familiar with the extraordinary resources offered by our library. Offered as CHEM 344 and CHEM 444. Prereq: CHEM 106.

CHEM 445. Electrochemistry I. 3 Units.
Electrochemical properties and processes of electrode/electrolyte interfaces. Fundamental background for work in corrosion, electrodeposition, industrial electrolysis, electro-organic synthesis, batteries, fuel cells, and photoelectrochemical energy conversion. Recommended preparation: One semester of undergraduate physical chemistry.

CHEM 446. Quantum Mechanics I. 3 Units.
Introduction of quantization, measurement and the Schrodinger equation; angular momentum and states of molecules. Perturbation theory, spectroscopy and chemical bonding. Variational theory and calculations of molecular properties. Recommended preparation: Two semesters of undergraduate physical chemistry. Offered as CHEM 335 and CHEM 446.

CHEM 448. Chemistry Fermentation Brewing: To Discern the Molecular Basis of Fermentation and Beer Brewing. 3 Units.
This course includes in-depth discussions of the chemistry and procedures underlying either an aspect of the brewing process or a style of beer in order to discern the molecular basis of fermentation and beer brewing. The biochemistry of yeast fermentation and hops, as well as mashing, lautering, boiling, conditioning, filtering, and packaging will be discussed. There is no lab component (such as brewing beer), although field trips to pubs including the Jolly-Scholar pub (located on campus) will be part of the course, as well as invited speakers who have set up local microbreweries. Each student will be expected to have basic background knowledge of chemistry, such as material taught in standard first year General Chemistry courses. Offered as CHEM 348 and CHEM 448. Prereq: CHEM 106 or ENGR 145.

CHEM 450. Modern Molecular Spectroscopy: Study of the Interactions Between Light and Matter. 3 Units.
This course is aimed to provide a modern treatment of molecular spectroscopy for physical chemists and for other related areas of interest. At the same time, it will attempt to serve the more generally interested science and engineering student to learn about the many interactions that light undergoes with matter. Offered as CHEM 350 and CHEM 450. Prereq: CHEM 446.

CHEM 475. Protein Biophysics. 3 Units.
This course focuses on in-depth understanding of the molecular biophysics of proteins. Structural, thermodynamic and kinetic aspects of protein function and structure-function relationships will be considered at the advanced conceptual level. The application of these theoretical frameworks will be illustrated with examples from the literature and integration of biophysical knowledge with description at the cellular and systems level. The format consists of lectures, problem sets, and student presentations. A special emphasis will be placed on discussion of original publications. Offered as BIOC 475, CHEM 475, PHOL 475, PHRM 475, and NEUR 475.

CHEM 506. Special Topics in Physical Chemistry. 1 - 6 Units.
(Credit as arranged.) Lectures on advanced topics in physical chemistry presented by staff or visiting lecturers. Course title, content, and credit change from year to year.

CHEM 507. Special Readings in Chemistry. 1 - 6 Units.
Detailed study of a special topic in chemistry under the guidance of a faculty member.

CHEM 508. Special Readings in Chemistry. 1 - 6 Units.
Detailed study of a special topic in chemistry under the guidance of a faculty member.

CHEM 601. Research. 1 - 18 Units.
(Credit as arranged.) Special research in an area of chemistry under the guidance of a faculty member.

CHEM 605. Chemistry Colloquium Series. 0 Unit.
Course content provided by Thursday chemistry department colloquia (or Frontiers in Chemistry lectures). Discussion sessions review previous lectures and lay foundation for forthcoming lectures.

CHEM 651. Thesis M.S.. 1 - 18 Units.
(Credit as arranged.)

CHEM 701. Dissertation Ph.D.. 1 - 9 Units.
(Credit as arranged.) Prereq: Predoctoral research consent or advanced to Ph.D. candidacy milestone.