# Chemistry and Biochemistry

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## INTRODUCTION

The UC San Diego Department of Chemistry and Biochemistry was founded in the 1950s by the late Professor Harold Urey and a group of colleagues who strove to create a department that would stress the fundamentals of chemistry and, at the same time, embrace diverse applications of those principles at the frontiers of knowledge.

Degrees offered include

### *Biochemistry*

- B.S. biochemistry/chemistry
- M.S. chemistry
- Ph.D. chemistry
- Ph.D. chemistry with specialization in bioinformatics

### *Chemistry*

- B.S. biochemistry/chemistry
- B.S. bioinformatics from the Department of Chemistry and Biochemistry
- B.S. chemical education
- B.S. chemical physics
- B.S. chemistry
- B.S. environmental chemistry
- B.S. molecular synthesis
- B.S. pharmacological chemistry
- M.S. chemistry
- Ph.D. chemistry
- Ph.D. chemistry with specialization in bioinformatics
- Ph.D. chemistry with specialization in computational science
- Ph.D. chemistry with specialization in multi-scale biology

## CHEMISTRY–PREMEDICAL MAJORS

Either a biochemistry/chemistry major or a chemistry major with appropriate choice of electives provides a strong background for students intending to pursue careers in the medical sciences.

Premedical students are encouraged to complete the three-quarter general chemistry series (Chem. 6A-B-C or 6AH-6BH-6CH) in their first year. Most medical schools require a full year of general chemistry, and may not accept Advanced Placement exam scores to satisfy admissions requirements. Students with Advanced Placement exam scores of 4 or 5 who plan to attend medical school should discuss their academic plan with an academic or career advisor early in their academic career. Students should complete the organic chemistry series (Chem. 140A-B-C) in their sophomore year.

The lower-division biology (BILD 1-2-3) series or equivalent is also required for most medical schools, along with certain upper-division biology courses, some of which may be counted toward the major requirements in chemistry. Students should meet with the department's undergraduate advisor early in order to plan their courses and discuss their options.

## GENERAL CHEMISTRY

The General Chemistry Chem. 6 sequence (6A-B-C) is intended for science and engineering majors as well as others who need a quantitative course. It satisfies all preprofessional programs. Chem. 4 is a one-quarter preparation for 6A, which should be taken only by those whose college advisor so recommends. The Honors General Chemistry sequence (6AH-6BH-6CH) is designed for science and engineering majors with strong preparation in science and mathematics. A student intending to major in chemistry can thus begin with 4, 6A, or 6AH depending on the level of preparation. A student intending to major in a discipline other than chemistry should consult his or her advisor in the appropriate department to determine which chemistry course is recommended.

Chem. 11, 12, 13 is a terminal sequence for non-science/non-engineering majors. Chem. 15 is a one-quarter survey course suitable for non-science majors. Students should check with their college advisor to determine applicability toward general-education requirements.

## GENERAL INFORMATION ON UNDERGRADUATE MAJOR PROGRAMS

The minimum passing grade is a D, though students may not graduate with more than one D grade in upper-division required course work and must maintain a minimum of a 2.0 GPA in the major. All courses for the major, except for independent research (Chem. 196 and 199) and chemistry instruction (Chem. 195), must be taken for a letter grade. Chem. 195, 196, and 199 must be taken on a P/NP basis. All chemistry majors, including transfer students, must complete forty-eight units of upper-division chemistry course work at UCSD and fulfill the campus senior residency requirement.

In addition to the requirements, Math. 20F (required for chemical physics majors) and a course in computer programming are also recommended.

Any departure from the requirements outlined below must be approved by petition. This applies to lower- and upper-division requirements.

The suggested programs following each of the major descriptions are only examples.

All undergraduate degree programs, unless otherwise noted, are certified by the American Chemical Society.

## BIOCHEMISTRY/CHEMISTRY MAJOR

The biochemistry/chemistry major deals with the chemical processes in living organisms, including structure and function of nucleic acids and proteins. It is suitable for those planning to go to graduate school as well as medical, dental, veterinary, and other professional schools. It is also suitable at the bachelor's level for jobs in the biotechnology or pharmaceutical field. Note the requirement for two advanced elective courses in biochemistry. If one does not wish to take so much biochemistry, one should major in chemistry and use some of the five electives to take the desired number of biochemistry courses.

The following courses must be taken for a letter grade:

### LOWER-DIVISION REQUIREMENTS

1. General chemistry including laboratory (Chem. 6A-C or 6AH-CH, and 7L, or equivalent).
2. Calculus (Math. 20A-D, or equivalent).
3. Calculus-based physics including laboratory (Phys. 2A-B and 2D or equivalent, and either 2BL, 2CL or 2DL. Phys. 2CL is recommended and is accessible without Phys. 2C).

### UPPER-DIVISION REQUIREMENTS

1. Three quarters of organic chemistry (Chem. 140A, B or BH, C or CH).
2. Two quarters of physical chemistry (Chem. 126-127 recommended, or the equivalent).
3. One quarter of inorganic chemistry (Chem. 120A).
4. Three quarters of biochemistry (Chem. 114A-C).
5. Six laboratory courses (Chem. 100A, 143AH or 143A, 143B, 105A, either 108 or 109 and one additional chemistry lab from the following: Chem. 100B-BL, 105B, 108 or 109, 123, 143C, or 143D).
6. Two elective courses from the following list: Chem. 104/204, 113/213, 114D, 116, 118, 124/225, 157/257, 164, 165, 166, 221, 280.
7. One additional elective course chosen from among all of the upper-division and graduate courses offered by the Department of Chemistry and Biochemistry (except non-letter-graded courses) or from the following list of courses offered by the Department of Biology (some biology courses will require additional course work to fulfill prerequisites): BICD 100, BICD 110, BICD 140, BIMM 114, BIMM 120, BIPN 100, BIPN 102, BIPN 140. Other electives, including Chem. 195 and Chem. 199, may be arranged by petition.

### SUGGESTED PROGRAM FOR BIOCHEMISTRY/CHEMISTRY B.S. MAJOR

Many courses have enforced prerequisites or are offered once per year.

| FALL | WINTER | SPRING |
|---|---|---|
| **FRESHMAN YEAR** | | |
| Chem. 6A | Chem. 6B | Chem. 6C |
| Math. 20A | Math. 20B | Chem. 7L |
| | BILD 1* | Math. 20C |
| **SOPHOMORE YEAR** | | |
| Chem. 100A | Chem. 140B | Chem. 140C |
| Chem. 140A | Chem. 143AH | Chem. 143B |
| Math. 20D | Phys. 2B | Phys. 2D |
| Phys. 2A | | |
| **JUNIOR YEAR** | | |
| Chem. 114A | Chem. 114B | Chem. 105A |
| Chem. 127 | Chem. 126 | Chem. 114C |
| Phys. 2CL | | |
| **SENIOR YEAR** | | |
| Chem. 120A | Elective Lab** | Elective Lab** |
| Elective | Elective | Elective |

*Recommended, but not required.

**One of these must be Chem. 108 or 109.

## BIOINFORMATICS MAJOR FROM THE DEPARTMENT OF CHEMISTRY AND BIOCHEMISTRY

*Also see the program information listed under "Bioinformatics" in the catalog.*

The Bioinformatics major offers a rigorous, interdisciplinary training in the new and rapidly evolving field of bioinformatics with a strong focus on chemistry and biochemistry. Bioinformatics is the field of advanced computational and experimental methods that model the flow of information (genetic, metabolic, and regulatory) in living systems to provide an integrated understanding of the systems properties of model organisms. This is a new and rapidly evolving field in which large volumes of both qualitative and quantitative data will accrue at an increasing pace, and the bioinformatician must have a substantial mastery of both the sciences and engineering. This interdisciplinary specialization will be offered jointly with computer science and engineering, bioengineering, and biological sciences, each with its own set of requirements and electives. The program offered by the Department of Chemistry and Biochemistry is aimed at a student interested in applying and developing tools of bioinformatics for the study of chemical processes in biological systems.

### ADMISSION TO THE BIOINFORMATICS MAJOR

Freshmen and transfer students are invited to declare to the Department of Chemistry and Biochemistry for a bioinformatics major. Starting fall 2008 the Department of Chemistry and Biochemistry has removed the "Impacted/Closed Status" and admission restrictions for freshmen and transfer applicants to the bioinformatics major. This means the Department of Chemistry and Biochemistry will accept all students that apply to the B.S. Bioinformatics major and are admitted by the UC San Diego Admissions Office.

Furthermore, freshmen and transfer students that start at UC San Diego as undeclared or another major may also switch into the B.S. Bioinformatics major in the Department of Chemistry and Biochemistry (major code CH37), via the Major/Minor link under Tools at http://tritonlink.ucsd.edu to make this change.

It is strongly recommended that students meet with an advisor in the Department of Chemistry and Biochemistry to discuss requirements for the Bioinformatics Program.

### LOWER-DIVISION REQUIREMENTS

1. Calculus and linear algebra (Math. 20A-20C, 20F)
2. General chemistry including laboratory (Chem. 6A-C or 6AH-CH, and 7L).
3. Physics (Phys. 2A-B)

4. Biology (BILD 1-2)
5. Computer programming (CSE 11-12)
6. Mathematics for algorithm and systems (CSE 21/ Math. 15B)
7. Bioinformatics seminar (BILD 94)

The department recommends that students complete an introductory C programming course before taking CSE 11 and CSE 12, either in their first year or during the summer between their first and second years.

### UPPER-DIVISION REQUIREMENTS

1. Two quarters of organic chemistry (Chem. 140A-B)
2. Organic chemistry (Chem. 140C) or structural biochemistry (Chem. 114A)
3. Metabolic biochemistry (Chem. 114B)
4. Physical chemistry (Chem. 127 accepted, Chem. 131 and 132 recommended)
5. Molecular and cellular biochemistry (Chem. 114D)
6. Two quarters of biochemistry laboratory (Chem. 108-109)
7. Genetics (BICD 100)
8. Cell biology (BICD 110)
9. Two computer science courses (CSE 100 or Math. 176; and CSE 101 or Math. 188)
10. Two additional upper-division electives offered by the Department of Chemistry and Biochemistry (each course must be at least four units) with only one quarter of credit allowed for any given course. Recommended courses are: Chem. 100A, 118, and 143A.

The bioinformatics series comprising the following courses:

11. Molecular sequence analysis (BIMM 181 or CSE 181 or BENG 181)
12. Biological databases (Chem. 182 or BIMM 182 or CSE 182 or BENG 182)
13. Applied genomic technologies (BENG 183)
14. Computational molecular biology (BIMM 184 or CSE 184 or BENG 184 or Chem. 184)
15. Bioinformatics lab (BIMM 185)
16. Probability and statistics (Math. 186)

### SUGGESTED PROGRAM FOR THE BIOINFORMATICS B.S. FROM THE DEPARTMENT OF CHEMISTRY AND BIOCHEMISTRY

Many courses have enforced prerequisites or are offered once per year.

| FALL | WINTER | SPRING |
|---|---|---|
| **FRESHMAN YEAR** | | |
| Chem. 6A | Chem. 6B | Chem. 6C |
| Math. 20A | BILD 1 | Chem. 7L |
| | Math. 20B | Math. 20C |
| | | BILD 94 |
| **SOPHOMORE YEAR** | | |
| CSE 11 | Chem. 140A | Chem. 109* |
| BILD 2 | CSE 12 | Chem. 140B |
| Phys. 2A | Phys. 2B | CSE 21/ Math. 15B |
| **JUNIOR YEAR** | | |
| Chem. 114A/140C | Chem. 114B* | Elective |
| Chem. 114D* | BICD 100 | BIMM 181/ BENG 181/ CSE 181 |
| CSE 100/ Math. 176 | Math. 186 | BICD 110 |
| Math. 20F | CSE 101/ Math. 188 | |
| **SENIOR YEAR** | | |
| Chem. 182/ BIMM 182/ BENG 182/ CSE 182 | Chem. 108* | BIMM 185 |
| BENG 183 | | Elective |
| Chem. 127* | BIMM 184/ BENG 184/ CSE 184 | |

*Certain prerequisite courses are waived for the bioinformatics majors. See the department advisor for details.

## CHEMICAL EDUCATION MAJOR

The chemical education major offers an excellent preparation for teaching physical science in secondary schools, including chemistry, physics, earth science, biology, and mathematics.

Students taking the minimal chemical education program may be admissible as graduate students in chemistry and biochemistry, but are better prepared for admission to teacher education programs at most universities. The ACS-Certified option will ensure admissibility to chemistry graduate programs. This program is also excellent preparation for students interested in a career in science writing.

The program is basically a chemistry major with three courses in chemistry for educators and three courses from Education Studies. Requirements allow some work in earth science and biology or other sciences.

If you are interested in earning a California teaching credential through UCSD, contact Education Studies for information about the prerequisite and professional preparation requirements. It is recommended that you contact Education Studies as early as possible in your academic career.

The following courses must be taken for a letter grade:

### LOWER-DIVISION REQUIREMENTS

1. General chemistry including laboratory (Chem. 6A-C or 6AH-CH, and 7L, or equivalent).
2. Calculus (Math. 20A-D, or equivalent).
3. Calculus-based physics including laboratory (Phys. 2A-B and 2D or equivalent, and either 2BL, 2CL or 2DL. Phys. 2CL is recommended and is accessible without Phys. 2C).
4. Biology (BILD 1).
5. Earth Science (SIO 50).
6. Introduction to Chemical Education (Chem. 96).

### UPPER-DIVISION REQUIREMENTS

1. Two quarters of organic chemistry (Chem. 140A-B).
2. Two quarters of physical chemistry (Chem. 126-127 recommended, or the equivalent).
3. Three quarters of chemistry for educators (Chem. 187 and two among Chem. 188, Chem. 195 (preferably with Chem. 4), Chem. 196, or Chem. 199)
4. Advanced chemistry (either Chem. 114A or 120A).
5. Three laboratory courses (Chem. 100A, 143AH or 143A, and 105A).
6. Three additional elective course chosen from among Chem. 114A, 114B, 114C, 120A, 140C, 149A, 149B, SIO 102, SIO 103, other upper-division and graduate courses offered by the Department of Chemistry and Biochemistry, or, by petition, from other natural science departments.
7. Three courses from Education Studies (EDS 129A-B-C).

### *For ACS Certification*

- 1. Take Chem. 114A, 120A, and 140C. Eliminate required electives above.
- 2. Three additional labs must be chosen from among Chem. 143B, 143C, 143D, 108, 109, 123, or 105B.
- 3. Only one among Chem. 188, Chem. 195 (preferably with Chem. 4), Chem. 196, or Chem. 199 is required.

### SUGGESTED PROGRAM FOR CHEMICAL EDUCATION B.S. MAJOR

Many courses have enforced prerequisites or are offered once per year.

| FALL | WINTER | SPRING |
|---|---|---|
| **FRESHMAN YEAR** | | |
| Chem. 6A | Chem. 6B | Chem. 6C |
| Math. 20A | BILD 1 | Chem. 96 |
| | Math. 20B | Math. 20C |
| **SOPHOMORE YEAR** | | |
| Chem. 7L | Chem. 140A | Chem. 140B |
| Math. 20D | Chem. 100A | Chem. 143A |
| Phys. 2A | Phys. 2B | Phys. 2D |
| **JUNIOR YEAR** | | |
| Chem. 127 | Chem. 126 | Phys. 105A |
| Phys. 2CL | Chem. 187 | Chem. 120A |
| SIO 50 | Elective | Elective |
| **SENIOR YEAR** | | |
| Elective | Chem. 196/199 | Chem. 188 |
| Chem. 195 | EDS 129B | EDS 129C |
| EDS 129A | | |

## CHEMICAL PHYSICS MAJOR

The chemical physics major applies the concepts and quantitative methods of physics to the descriptions of atoms and molecules, analyzes matter as a statistical assembly of molecular building blocks, and develops and exploits physical (largely spectroscopic), experimental tools with which to test and refine such theories.

The chemical physics major is designed as a preparation for graduate work in chemistry, physics, or other interdisciplinary areas.

The following courses must be taken for a letter grade:

### LOWER-DIVISION REQUIREMENTS

1. General chemistry including laboratory (Chem. 6A-C or 6AH-CH, and 7L, or equivalent).
2. Calculus and linear algebra (Math. 20A-F, or equivalent).
3. Calculus-based physics including laboratory (Phys. 2A-D or equivalent, and either 2BL, 2CL or 2DL. Phys. 2CL is recommended).

It is recommended that the above requirements be completed by the end of the sophomore year.

### UPPER-DIVISION REQUIREMENTS

1. Two quarters of organic chemistry (Chem. 140A-B).
2. One year of physical chemistry (Chem. 131-133).
3. Two quarters of inorganic chemistry (Chem. 120A-B). Chem. 114A can substitute for Chem. 120B.
4. Six upper-division chemistry labs: Chem. 100A, 100B-BL, 143AH or 143A, 143B or 143C, 105A and one of the following: 105B, 108, 109, 123, 143B, 143C, or 143D.
5. Molecular spectroscopy (Chem. 135).
6. Partial differential equations (Math. 110).
7. Two quarters of physics (Phys. 110A-B, or Phys. 100A-B).
8. One additional course in physical chemistry or related areas as approved by the department. Chem. 199 may be petitioned.

### SUGGESTED PROGRAM FOR CHEMICAL PHYSICS B.S. MAJOR

Many courses have enforced prerequisites or are offered once per year.

| FALL | WINTER | SPRING |
|---|---|---|
| **FRESHMAN YEAR** | | |
| Chem. 6A | Chem. 6B | Chem. 6C |
| Math. 20A | Math. 20B | Chem. 7L |
| | | Math. 20C |
| | | Phys. 2A |
| **SOPHOMORE YEAR** | | |
| Chem. 140A | Chem. 140B | Chem. 100A |
| Math. 20D | Chem. 143AH | Math. 20F |
| Phys. 2B | Math. 20E | Phys. 2D |
| | Phys. 2C | |
| **JUNIOR YEAR** | | |
| Chem. 133 | Chem. 131 | Chem. 100B-BL |
| Chem. 143C | Phys. 2CL | Chem. 132 |
| Phys. 110A/ 100A | Phys. 110B/ 100B | Math. 110 |
| **SENIOR YEAR** | | |
| Chem. 105A | Elective Lab | Chem. 135 |
| Chem. 120A | Chem. 120B* | Elective |

*Chem. 114A (fall or winter quarter) may be substituted.

## CHEMISTRY MAJOR

The chemistry major provides a broad introduction for the biochemistry, organic, physical, or inorganic student as well as those who prefer not to specialize. This major will enable a student to pursue further studies in chemistry or in related fields of science, medicine, or engineering.

The following courses must be taken for a letter grade:

### LOWER-DIVISION REQUIREMENTS

1. General chemistry including laboratory (Chem. 6A-C or 6AH-CH, and 7L, or equivalent).
2. Calculus (Math. 20A-D, or equivalent).
3. Calculus-based physics including laboratory (Phys. 2A-B and 2D or equivalent, and either 2BL, 2CL or 2DL. Phys. 2CL is recommended and is accessible without Phys. 2C).

### UPPER-DIVISION REQUIREMENTS

1. Three quarters of organic chemistry (Chem. 140A-C).
2. Three quarters of physical chemistry (Chem. 131–133).
3. Two quarters of inorganic chemistry Chem. (120A-B).
4. One quarter of biochemistry (Chem. 114A).
5. Six laboratory courses (Chem. 100A, 143AH or 143A, 143B, 105A and two of the following: Chem. 100B-BL, 105B, 108, 109, 123, 143C, or 143D).
6. Three additional four-unit upper-division or graduate courses in chemistry and biochemistry or related areas. One of Chem. 195 or 199 may be petitioned.

### SUGGESTED PROGRAM FOR CHEMISTRY B.S. MAJOR

Many courses have enforced prerequisites or are offered once per year.

| FALL | WINTER | SPRING |
|---|---|---|
| **FRESHMAN YEAR** | | |
| Chem. 6A | Chem. 6B | Chem. 6C |
| Math. 20A | Math. 20B | Chem. 7L |
| | | Math. 20C |
| **SOPHOMORE YEAR** | | |
| Chem. 100A | Chem. 140B | Chem. 140C |
| Chem. 140A | Chem. 143AH | Chem. 143B |
| Math. 20D | Phys. 2A | Phys. 2B |
| **JUNIOR YEAR** | | |
| Chem. 120A | Chem. 120B | Chem. 105A |
| Chem. 133 | Chem. 131 | Chem. 132 |
| Phys. 2D | Phys. 2CL | |
| **SENIOR YEAR** | | |
| Chem. 114A | Elective Lab | Elective |
| Elective Lab | Elective | Elective |

## ENVIRONMENTAL CHEMISTRY MAJOR

Students have an option of earning a B.S. in environmental chemistry that is ACS-Certified or not. The ACS-Certified version is recommended for those who intend to apply to graduate school in chemistry. The noncertified program is designed to prepare students to enter the industrial, governmental, or legal workforce, or to continue studies in some of the environmental sciences.

The following courses must be taken for a letter grade, except where that is not permitted:

### LOWER-DIVISION REQUIREMENTS

1. General chemistry including laboratory (Chem. 6A-C or 6AH-CH, and 7L, or equivalent).
2. Calculus (Math. 20A-D, or equivalent).
3. Calculus-based physics including laboratory (Phys. 2A-B and 2D or equivalent, and either 2BL, 2CL or 2DL. Phys. 2CL is recommended and is accessible without Phys. 2C)

### UPPER-DIVISION REQUIREMENTS

1. Two quarters of organic chemistry (Chem. 140A-B).
2. Physical chemistry (Chem. 131-133 recommended, or Chem. 126-127).
3. Four advanced laboratory courses (Chem. 100A, 100B-BL, 105A, and 143AH or 143A).
4. Two quarters of environmental chemistry (Chem. 149A-B).
5. Atmospheric chemistry (Chem. 173) and marine chemistry (Chem. 174).
6. Electives: Any four with at least two upper-division among: Chem. 114A, 120A, 140C, 143C, 166, BILD 1, 2, 3, BIEB 121, 140, 144, 176, ESYS 101, SIO 50, 101, 102, 103, 144, Math. 183, or others (including labs) by petition. One of 195 or 199 by petition.

### *For ACS Certification*

1. Increase electives by one to a total of five.
2. For three of the electives, choose Chem. 140C, 114A, and 120A,
3. For two of the electives, choose two labs from among Chem. 143B, 143C, 143D, 108, 109, 123, 105B.

### *Recommended, but not Required, Electives*

- Nonscience elective courses used to meet general-education requirements or as free electives might be chosen from among: Econ. 1, 2, 3, 131, 132, HIUS 154, Phil. 148, 164, Poli. Sci. 10, 160AA, 162, Soc. 185, USP 2, 124, 144, 171.

### SUGGESTED PROGRAM FOR ENVIRONMENTAL CHEMISTRY B.A. OR B.S. MAJOR (B.S. AND ACS CERTIFICATION REQUIRE ADDITIONAL COURSES)

Many courses have enforced prerequisites or are offered once per year.

| FALL | WINTER | SPRING |
|---|---|---|
| **FRESHMAN YEAR** | | |
| Chem. 6A | Chem. 6B | Chem. 6C |
| Math. 20A | Math. 20B | Chem. 7L |
| | Phys. 2A | Math. 20C |
| **SOPHOMORE YEAR** | | |
| Chem. 100A | Chem. 140B | Phys. 2CL |

| | | |
|---|---|---|
| Chem. 140A | Chem. 143AH | Phys. 2D |
| Math. 20D | Phys. 2B | |
| **JUNIOR YEAR** | | |
| Chem. 133 | Chem. 131 | Chem. 132 |
| Chem. 149A | Chem. 149B | Chem. 173 |
| Elective | Elective | Elective |
| **SENIOR YEAR** | | |
| Chem. 105A | Chem. 100B-BL | Chem. 174 |
| Elective | | |

*Chem. 140C may be substituted.

## MOLECULAR SYNTHESIS MAJOR

The molecular synthesis major offers a thorough training in all aspects of the molecular synthesis of organic, inorganic, and biological substances, and with a fundamental understanding of their structure and reactivity. This major provides an excellent preparation for employment in biotechnology, diagnostic, electronic, and pharmaceutical enterprises as well as for graduate programs in organic, bioorganic, and inorganic chemistry.

The following courses must be taken for a letter grade:

### LOWER-DIVISION REQUIREMENTS

1. General chemistry including laboratory (Chem. 6A-6C or 6AH-CH and 7L, or equivalent)
2. Calculus (Math. 20A-D, or equivalent).
3. Calculus-based physics including laboratory (Phys. 2A-B and 2D or equivalent, and either 2BL, 2CL or 2DL. Phys. 2CL is recommended and is accessible without Phys. 2C).

### UPPER-DIVISION REQUIREMENTS

1. Three quarters of organic chemistry (Chem. 140A-C).
2. Three quarters of physical chemistry (Chem. 131-133).
3. Two quarters of inorganic chemistry (Chem. 120A-B).
4. One quarter of biochemistry (Chem. 114A).
5. Six laboratory courses (Chem. 100A, 143A or 143AH, 143B, 143C, or 143D, 105A, and 123).
6. Synthetic methods (Chem. 152).
7. Structural or mechanistic organic chemistry (Chem. 154 or 156).
8. Bioorganic or bioinorganic chemistry (Chem. 124 or 157).
9. One additional course from the following: Chem. 114B, 114C, 155, 185, or 199.

### SUGGESTED PROGRAM FOR MOLECULAR SYNTHESIS B.S. MAJOR

Many courses have enforced prerequisites or are offered once per year.

| FALL | WINTER | SPRING |
|---|---|---|
| **FRESHMAN YEAR** | | |
| Chem. 6A | Chem. 6B | Chem. 6C |
| Math. 20A | Math. 20B | Chem. 7L |
| | | Math. 20C |
| **SOPHOMORE YEAR** | | |
| Chem. 100A | Chem. 140B | Chem. 140C |
| Chem. 140A | Chem. 143AH | Chem. 143B |
| Math. 20D | Phys. 2B | Phys. 2CL |
| Phys. 2A | | Phys. 2D |
| **JUNIOR YEAR** | | |
| Chem. 120A | Chem. 120B | Chem. 105A |
| Chem. 133 | Chem. 123 | Chem. 132 |
| Chem. 143C* | Chem. 131 | |
| **SENIOR YEAR** | | |
| Chem. 114A | Chem. 154/156 | Chem. 107/124/157 |
| Chem. 152 | Elective | |

*Chem. 143D may be substituted.

## PHARMACOLOGICAL CHEMISTRY MAJOR

The pharmacological chemistry major provides a strong background in chemistry and includes most courses required by California pharmacy schools. The major is intended primarily to prepare students for pharmacy school (Pharm.D.). Students fulfilling their elective requirements with appropriate courses would be prepared for graduate school to obtain a Ph.D. in pharmacology, biochemistry, or other areas of science. Degree recipients would also be prepared for most jobs in the biotechnology and chemical industries.

Pharmacological chemistry students are strongly encouraged to complete a full year of general chemistry and a full year of lower-division biology. As with some medical programs, some pharmacy programs may require a full year of these courses and may not accept tests such as the Advanced Placement exam to satisfy these requirements.

The following courses must be taken for a letter grade:

### LOWER-DIVISION REQUIREMENTS

1. Biology (BILD 1, 2 and 3, and either BICD 101, 111, 131, or BIPN 105 or BIMM 121). Alternatively, a year of biology with laboratory at a community college may be petitioned.
2. General chemistry including laboratory (Chem. 6A-C or 6AH-CH, and Chem. 7L, or equivalent).
3. Calculus-based physics including laboratory. (Phys. 2A-B and 2D or equivalent, and either 2BL, 2CL, or 2DL. Phys. 2CL is recommended and is usually the course required by pharmacy schools. It is accessible without Phys. 2C).
4. Calculus (Math. 20A–D, or equivalent).
5. Economics (Econ. 1 or 3 or equivalent).
6. Pharmacology seminar (Chem. 92).

Most California pharmacy schools require a course in public speaking for admission to the school. Students planning to apply to these programs should take Public Speaking, TDGE 25, or an appropriate course at a community college.

### UPPER-DIVISION REQUIREMENTS

1. Two quarters of physical chemistry (Chem. 126-127 recommended; 131–133 acceptable).
2. Three quarters of organic chemistry (Chem. 140A-C).
3. Three quarters of biochemistry (Chem. 114A-B-C).
4. Four laboratory courses (Chem. 100A, 143AH or 143A, 143B and either 108, 109, or 143C).
5. One quarter of pharmacology and toxicology (Chem. 118).
6. One chemistry elective course chosen from among all the upper-division and graduate courses offered by the Department of Chemistry and Biochemistry (except non-letter graded courses).

If ACS certification is desired, Chem. 120A, plus two additional laboratory courses (Chem. 105A and a lab chosen from Chem. 100B-BL, 105B, 123, or 143C/108/109, if not already taken), are required. Any of these courses would satisfy number 6 above.

### SUGGESTED PROGRAM FOR PHARMACOLOGICAL CHEMISTRY B.S. MAJOR (ACS CERTIFICATION REQUIRES ADDITIONAL COURSES)

Many courses have enforced prerequisites or are offered once per year.

| FALL | WINTER | SPRING |
|---|---|---|
| **FRESHMAN YEAR** | | |
| Chem. 6A | Chem. 6B | Chem. 6C |
| Math. 20A | Math. 20B | Chem. 7L |
| | BILD 1 | Chem. 92 |
| | | Math. 20C |
| **SOPHOMORE YEAR** | | |
| Chem. 100A | Chem. 140B | Chem. 140C |
| Chem. 140A | Chem. 143AH | Chem. 143B |
| Math. 20D | Phys. 2A | Phys. 2B |
| **JUNIOR YEAR** | | |
| Chem. 114A | Chem. 114B | Chem. 114C |
| Phys. 2D | Econ. 1/3 | BILD 3 |
| | BILD 2 | Phys. 2CL |
| **SENIOR YEAR** | | |
| Chem. 127 | Chem. 126 | Chem. 118 |
| Lab* | Bio. lab** | |

*Chem. 108 or 109 or 143C.

**BICD 101, 111, 131, or BIPN 105 or BIMM 121 (some have prerequisites that must be taken in an earlier quarter).

## HONORS PROGRAM

The Department of Chemistry and Biochemistry offers an Honors Program to those students who have demonstrated excellence in any of the nine majors. Students are eligible for Departmental Honors at graduation when they have

1. Achieved a GPA of 3.2 overall and 3.4 in chemistry courses.
2. Completed a minimum of eight units of Chem. 199, distributed over at least two quarters. A student who registers for 199 and subsequently fails to complete the Honors Program may apply up to four units to any major that normally allows 199 as elective credit. A student who has successfully petitioned to use a Chem 199 course to fulfill elective credit may not use that course to fulfill honors requirements as well.
3. Submitted a final honors research report to three UCSD faculty members, including their research advisor, for approval.

4. Presented an oral report about their research before a group of at least three faculty. This can be at an undergraduate research conference or at a seminar involving honors students and faculty.

Students who are interested in the Honors Program should contact the Undergraduate Advising Office in 4010 York Hall, and are invited to do so at any time.

## EDUCATION ABROAD

Majors are encouraged to explore the programs that allow students to study abroad or at other U.S. universities for a term or longer. See an advisor for details.

Chemistry and Biochemistry majors are encouraged to participate in the UC Education Abroad Program (EAP) and UCSD's Opportunities Abroad Program (OAP). Subject to approval by our faculty, courses taken through EAP/OAP may be accepted for credit toward the major. Students interested in studying abroad should see a departmental program advisor to discuss appropriate courses and programs for their plan of study.

## MINOR PROGRAM IN CHEMISTRY AND BIOCHEMISTRY

A typical minor in chemistry consists of three lower-division lecture courses and at least one laboratory course, followed by a minimum of five upper-division courses, including at least one laboratory course, focused in physical, inorganic, organic, environmental chemistry, or biochemistry. Lower-division course requirements may not be satisfied by advanced placement credit, though transfer units may be used to satisfy lower-division minor requirements.

Upper-division courses required by a student's major may not be applied toward a minor.

Upper-division courses for the minor must be taken at UCSD in the Department of Chemistry and Biochemistry, and must be taken for a letter grade. The minimum overall GPA requirement for the minor is a 2.0.

## THE GRADUATE PROGRAMS

Graduate students are accepted to the Department of Chemistry and Biochemistry for study toward Plan I (Thesis) and the Plan II (Comprehensive Examination) M.S. in chemistry, the Ph.D. in chemistry, the Ph.D. in chemistry with specialization in bioinformatics, the Ph.D. with specialization in computational science, and the Ph.D. with specialization in multi-scale biology. Students interested in the bioinformatics specialization should contact the Student Affairs Office for more information.

### MASTER'S OF SCIENCE

A Plan I (Thesis) M.S. in chemistry and a Plan II (Comprehensive Examination) M.S. in chemistry are offered.

Admissions: UC San Diego students are admitted for fall, winter, and spring quarter entrance; non-UCSD students are normally admitted for fall entrance only. Eligibility requirements for admission include a solid training in the chemical sciences based on the undergraduate record, a 3.0 GPA in chemistry courses completed, and a 3.0 overall GPA.

The GRE general test is required of all applicants. Foreign applicants must submit a TOEFL score; TWE scores are strongly recommended. Those who wish to apply to the Thesis Plan must have a letter of support from the proposed thesis advisor.

Residency and Time to Degree: Master's students must register at UCSD for a minimum of three quarters, and complete at least twenty units per academic year. Full-time Comprehensive Examination Plan students can complete the degree in three quarters. Thesis Plan students typically take eighteen to twenty-four months to graduate.

Relationship to Doctoral Program: Master's students who wish to continue their studies as doctoral students in chemistry and biochemistry must request to transfer to that program. Application materials are due mid-January and include current letters of recommendation, current UCSD transcript, and statement of purpose. Transfer is for fall quarter only.

#### *Plan I (Thesis)*

Purpose: To prepare students for research careers or for doctoral or professional studies; the emphasis is on research.

Advancement to Candidacy: A minimum of thirty-six units with an overall GPA of 3.0 must be completed. The majority of units taken are for thesis research (Chem. 299). At least eight units of graduate level chemistry courses must be completed for a letter grade. Four units of teaching apprenticeship are required (Chem. 500; see Doctoral Program, Teaching and Language Requirement sections). Contact the Student Affairs Office for full information.

Thesis: Students must give an oral presentation and defense of their thesis project to a Thesis Committee. A student graduates after the thesis has been defended and the written dissertation approved by his or her committee, department, and OGSR, and filed with the University Archivist. The Thesis Committee consists of at least three faculty: (1) the thesis advisor, (2) a faculty member from the Department of Chemistry and Biochemistry familiar with the student's research area, and (3) a faculty member from either this or another department whose research is in an area different from that of the thesis.

#### *Plan II (Comprehensive Exam)*

Purpose: To prepare students for doctoral or professional studies, teaching at the community college or high school level, or sometimes career work in industry; the emphasis is on course work.

Advancement to Candidacy: A minimum of thirty-six units with an overall GPA of 3.0 must be completed. The majority of units taken are in letter-graded graduate chemistry courses. Four units of teaching apprenticeship are required (Chem. 500; see Doctoral Program, Teaching and Language Requirement sections). Four units of nonthesis research (Chem. 297) are allowed. Contact the Student Affairs Office for full information.

Comprehensive Examination: The purpose of this requirement is to confirm that students have achieved an advanced understanding of, and a comprehensive training in, the chemical sciences. The tests cover a wide range of material, so that students will have a chance to show what they have learned. For master's students, the department administers the standardized American Chemical Society exams in biochemistry and in analytical, inorganic, organic, and physical chemistry. Students must pass three of the five exams in order to graduate. For doctoral students earning the M.S. on the way to the Ph.D., the Departmental Examination fulfills this requirement.

### DOCTORAL PROGRAM

The goal of the Ph.D. in chemistry is to prepare students for careers in science by expanding their knowledge of chemistry while developing their ability for critical analysis, creativity, and independent study. The program is designed to encourage initiative and to stimulate enjoyment and development of the student's area of research expertise as well as the broader aspects of scientific inquiry and enlightenment.

### RESEARCH

Students choose their research concentration from programs in biochemistry, biophysics, bioinformatics, inorganic, organic, physical, analytical, and theoretical chemistry, surface and materials chemistry, and atmospheric and environmental chemistry. Opportunities for scientific discovery are also abundant through the department's extensive collaborations with investigators in the physical, biological, and engineering sciences. This includes on-campus collaborations with faculty in the Materials Science Program, School of Medicine, School of Pharmacy and Pharmaceutical Sciences, and Scripps Institution of Oceanography. There are also off-campus interactions with scientists at nearby research facilities such as the Salk Institute and The Scripps Research Institute. Excellent state-of-the-art facilities and equipment support all the research programs. The department's Industrial Relations Program interfaces with national and local chemical, biotechnology, and pharmaceutical industries to encourage technology transfer and to assist postgraduates interested in industrial careers.

### RESEARCH ADVISOR

A first-year faculty advisor guides students until a research advisor is chosen. Most of a student's efforts in graduate school are directed toward research for the doctoral dissertation, and selection of a research advisor is of utmost importance. To assist students with this critical decision, all chemistry and biochemistry faculty present research seminars in the fall quarter. Students then rotate in laboratories or consult with faculty to discuss research opportunities. Although students have until the end of the first year to join a laboratory, most start their research studies by mid-year.

### PLACEMENT EXAMINATIONS AND COURSE WORK

Entering students take written placement examinations in analytical, biochemistry, inorganic, organic, and physical chemistry. The purposes of these exams are to assist with advising and to assure that students have the breadth and level

of competence needed for graduate studies. Deficiencies must be remedied in the first year. Three of five exams must be passed, including the one in the student's research area.

First-year students normally take at least six of the graduate courses listed below based on the results of their placement examinations, their research programs, and their specialized interests. Chem. 250 and Chem. 500 are required. Undergraduate courses and courses offered through other departments may also be taken, depending on the student's research area. By the second year, the emphasis is on thesis research, and a lighter load of courses is taken, although participation in seminars and informal study groups continues.

### DEPARTMENTAL EXAMINATION

In the winter quarter of the second year, a student's progress in research and graduate studies is evaluated through the departmental examination, which includes presentation and critical discussion of a recent research article. Students are also evaluated on their general knowledge of their particular field of study. Students may also be asked about progress on their dissertation.

### QUALIFYING EXAMINATION

By the end of the third year, students defend the topic, preliminary findings, and future research plans of their dissertation. Passing this defense qualifies the student to advance to candidacy for the dissertation. A dissertation committee composed of five faculty, one of whom is the research advisor, provides consultation and evaluation for the dissertation project.

### DISSERTATION

The dissertation is normally completed in the fourth or fifth year. This body of research is expected to make an innovative contribution to the field of chemistry. Ph.D. candidates present a seminar summarizing their research accomplishments and defend their thesis in an oral examination before their dissertation committee.

### TEACHING

Experience in teaching is a vital and integral part of every graduate student's training, and all students participate in the instructional activities of the undergraduate curriculum. Course credit for the teaching apprenticeship is earned by enrolling in Chem. 500. Excellence in teaching is stressed, and the department provides a thorough training program covering the fundamentals of teaching as well as other useful information and techniques for effective instruction. Further training is provided by the campus's Center for Teaching Development. Faculty and the students taught evaluate the performance of teaching assistants every quarter and awards are bestowed annually for outstanding performance as a teaching assistant.

### LANGUAGE REQUIREMENT

Students whose native language is not English must demonstrate a mastery of English adequate to complete the teaching requirement. Deficiencies must be remedied by the end of the first year of academic residency. For native English speakers, there is no foreign-language requirement.

## TIME LIMITS

In accordance with UCSD policy, students must advance to candidacy by the end of four years. Total university support cannot exceed six and one-third years. Total registered time at UCSD cannot exceed seven and one-third years.

## SEMINARS

Seminars by researchers from other universities, national laboratories, and industry are another basic and important aspect of the graduate curriculum. Seminars are presented weekly in biochemistry, inorganic, organic, and physical chemistry. Department colloquia are given on topics of general interest to the department. Seminars are also sponsored by many other departments and institutes.

## FINANCIAL SUPPORT

The department supports all first-year students in good academic standing from a variety of sources, including teaching and research assistantships, training grants, fellowships, and awards. A stipend is paid in addition to fees and, if applicable, tuition. Continuing students who do not have fellowships or awards are normally supported on training grants or on research assistantships by their thesis advisors.

## ADMISSIONS

The department seeks bright, motivated doctoral students and welcomes all such applications. To make admissions decisions, the department considers an applicant's statement of purpose and research interests, GRE scores on the general test plus either the advanced chemistry or advanced biochemistry test, undergraduate record, quality of the undergraduate university, letters of recommendation, and research experience and publications. Applicants whose native language is not English must also submit TOEFL scores; TWE scores are strongly recommended. Admissions to the doctoral program is for fall quarter. Applications received by mid-January receive priority consideration.

Students who have a master's degree with strong course records and with research experience are encouraged to apply. They normally pass the qualifying examination and graduate at an accelerated pace.

## PH.D. IN CHEMISTRY WITH SPECIALIZATION IN COMPUTATIONAL SCIENCE

As of fall 2007, the UCSD campus is offering a new comprehensive Ph.D. specialization in Computational Science that will be available to doctoral candidates in participating science, mathematics, and engineering departments at UCSD.

This Ph.D. specialization is designed to allow students to obtain standard basic training in their chosen field of science, mathematics, or engineering with a specialization in computational science integrated into their graduate studies. Prospective students must apply and be admitted into the Ph.D. program in Chemistry/Biochemistry described previously. (See the Department of Chemistry & Biochemistry for more information.)

## PH.D. IN CHEMISTRY & BIOCHEMISTRY WITH SPECIALIZATION IN MULTI-SCALE BIOLOGY

As of fall 2009, the UCSD campus is offering a new Ph.D. specialization in Multi-Scale Biology that will be available to doctoral candidates in participating programs that span four divisions: Biological Sciences, Physical Sciences, Jacobs School of Engineering, and Health Sciences at UCSD.

The Ph.D. specialization is designed to allow students to obtain standard basic training in their chosen field within the biological sciences, physical sciences, engineering, and health sciences with training in integrative and quantitative analysis across multiple scales of biological organization from molecule to organism in health and disease into their graduate studies. It trains a new cadre of Ph.D. scientists and provides a unique interdisciplinary education at the interfaces between the biological, medical, physical, and engineering sciences. (See the Department of Chemistry & Biochemistry for more information.)

## JOINT DOCTORAL PROGRAM WITH SAN DIEGO STATE UNIVERSITY

The Department of Chemistry and Biochemistry at UCSD and the Department of Chemistry at San Diego State University offer a joint program of graduate study leading to the Ph.D. degree in chemistry. More information is available in the current edition of the Bulletin of the Graduate Division of San Diego State University.

# COURSES

*For course descriptions not found in the UC San Diego General Catalog, 2010–11, please contact the department for more information.*

## LOWER-DIVISION

**4. Basic Chemistry (4)**
Chemistry 4 is a one-quarter course for science majors with insufficient preparation to start the Chem. 6 sequence. Emphasis is on learning how to solve quantitative problems. Topics include nomenclature, stoichiometry, and the periodic table. Cannot be taken for credit after any other chemistry course. Includes a laboratory/discussion each week. (F)

**6A. General Chemistry I (4)**
First quarter of a three-quarter sequence intended for science and engineering majors. Topics include: atomic theory, bonding, molecular geometry, stoichiometry, gas laws, solids and solutions, and thermochemistry. (F,W,S)

**6AH. Honors General Chemistry I (4)**
First quarter of a three-quarter honors sequence intended for well-prepared science and engineering majors. Topics are similar to those in 6A but are taught at a higher lever and faster pace. Students completing 6AH may not subsequently take 6A for credit. (F)

**6B. General Chemistry II (4)**
Second quarter of a three-quarter sequence intended for science and engineering majors. Topics include: three laws of thermodynamics, physical equilibria, chemical equilibria, acids and bases, solubility. **Prerequisites:** Chem. 6A or 6AH, Math. 10A or 20A. (F,W,S)

**6BH. Honors General Chemistry II (4)**
Second quarter of a three-quarter honors sequence intended for well-prepared science and engineering majors. Topics include: chemical equilibrium, acids and bases, and thermodynamics. Three hours lecture and one hour recitation. Students completing 6BH may not subsequently take 6B for credit. **Prerequisites:** Chem. 6AH and Math. 20A. (W)

**6C. General Chemistry III (4)**
Third quarter of a three-quarter sequence intended for science and engineering majors. Topics include: electrochemistry, kinetics, coordination chemistry, nuclear chemistry, and an introduction to organic and biochemistry. **Prerequisite:** Chem. 6B or 6BH. (F,W,S)

**6CH. Honors General Chemistry III (4)**
Third quarter of a three-quarter honors sequence intended for well-prepared science and engineering majors. Topics are similar to those in 6C but are taught at a higher level and faster pace. Students completing 6CH may not subsequently take 6C for credit. **Prerequisites:** Chem. 6BH and Math. 20B. (S)

**7L. General Chemistry Laboratory (4)**
Condenses a year of introductory training in analytical, inorganic, physical, and synthetic techniques into one intensive quarter. A materials fee is required. A mandatory safety exam must be passed. **Prerequisite:** Chem. 6B or Chem. 6BH. (F,W,S)

**11. The Periodic Table (4)**
Introduction to the material world of atoms and small inorganic molecules. Intended for nonscience majors. Can be skipped by students with a good knowledge of high school chemistry. Cannot be taken for credit after any other general chemistry course. (F)

**12. Molecules and Reactions (4)**
Introduction to molecular bonding and structure and chemical reactions, including organic molecules and synthetic polymers. Intended for nonscience majors. **Prerequisite:** Chem. 11 or good knowledge of high school chemistry. Cannot be taken for credit after any organic chemistry course. (W)

**13. Chemistry of Life (4)**
Introduction to biochemistry for nonscience majors. **Prerequisite:** Chem. 12. Cannot be taken for credit after any biochemistry course. (S)

**15. Chemistry of the Universe (4)**
This is a one-quarter, nonmathematical chemistry course for nonscience majors covering the origin of the universe, the elements, and the formation of the solar system. The evolution of the Earth's atmosphere, hydrosphere, geosphere, and biosphere will be covered, as well as contemporary problems in environmental chemistry. Cannot be taken for credit after any other chemistry course.

**87. Freshman Seminar in Chemistry and Biochemistry (1)**
This seminar will present topics in chemistry at a level appropriate for first-year students.

**90. Undergraduate Seminar (1)**
The seminar will focus on a variety of issues and special areas in the field of chemistry.

**91. Undergraduate Honors Seminar (1)**
A seminar intended for exposing undergraduate students, especially freshmen and sophomores, to exciting research programs conducted by the faculty. Enrollment is limited.

**92. Undergraduate Pharmacology Seminar (1)**
Selected topics in pharmacology and toxicology. (S)

**96. Introduction to Teaching Science (2)**
(Cross-listed with EDS 31.) Explores routine challenges and exceptional difficulties students often have in learning science. Prepares students to make meaningful observations of how K–12 teachers deal with difficulties. Explores strategies that teachers may use to pose problems that stimulate students' intellectual curiosity.

**99. Independent Study (2 or 4)**
Independent literature or laboratory research by arrangement with and under the direction of a member of the Department of Chemistry and Biochemistry faculty. Students must register on a P/NP basis. **Prerequisites:** lower-division standing, 3.0 minimum UCSD GPA, consent of instructor and department, completion of thirty units of undergraduate study at UCSD, completed and approved Special Studies form.

**99R. Independent Study (1)**
Independent study or research under the direction of a member of the faculty. **Prerequisites**: Student must be of first year standing and a Regent's Scholar; approved Special Studies form.

## UPPER-DIVISION

**100A. Analytical Chemistry Laboratory (4)**
Laboratory course emphasizing classical quantitative chemical analysis techniques, including separation and gravimetric methods, as well as an introduction to instrumental analysis. **Prerequisites:** Chem. 6C or 6CH or equivalent, and Chem. 6BL or equivalent; Phys. 2CL or 2BL recommended. A materials fee is required for this course. A mandatory safety exam must be passed within the first two weeks. (F,W,S)

**100B. Fundamentals of Instrumental Analysis (2)**
Fundamental theoretical principles, capabilities, applications, and limitations of modern analytical instrumentation used for qualitative and quantitative analysis. Students will learn how to define the nature of an analytical problem and how to select and appropriate analytical method. **Prerequisites:** Chem. 100A or graduate standing, and Phys. 2A-B-D or equivalent; Phys. 2CL or 2BL recommended. (Note: Students may not receive credit for both Chem. 100B and Chem. 106.) (F,W,S)

**100BL. Instrumental Analysis Laboratory (3)**
Hands-on laboratory course focuses on the development of correct laboratory work habits and methodologies for the operation of modern analytical instrumentation. Gas chromatography, gas-chromatography-mass spectrometry, high performance liquid chromatography, ion chromatography, atomic absorption spectroscopy. Chem. 100BL is for undergraduates only. **Prerequisites:** Chem. 100A; Phys. 2A-2B-2D, or equivalent; concurrent enrollment with Chem. 100B. Phys. 2BL or 2CL recommended. (Note: Students may not receive credit for both Chem. 100B and Chem. 106.) (F,W,S)

**104. Introduction to X-ray Crystallography (4)**
(Conjoined with Chem. 204.) Analysis of macromecular structures by X-ray diffraction. Topics include symmetry, geometry of diffraction, detection of diffraction, intensity of diffracted waves, phase problem and its solution, heavy atom method, isomorphous replacement, anomalous dispersion phasing methods (MAD), direct methods, molecular replacement. **Prerequisites:** Phys. 2A–B.

**105A. Physical Chemistry Laboratory (4)**
Laboratory course in experimental physical chemistry. **Prerequisites:** Chem.100A and Phys. 2CL, Chem. 126 or 127 or 131 or 133. A materials fee is required for this course. (F,W,S)

**105B. Physical Chemistry Laboratory (4)**
Laboratory course in experimental physical chemistry. **Prerequisite:** Chem. 105A. A materials fee is required for this course. (F,W,S)

**108. Protein Biochemistry Laboratory (6)**
The application of techniques to study protein structure and function, including electrophoresis, protein purification, column chromatography, enzyme kinetics, and immunochemistry. **Prerequisites:** Chem. 143A and Chem. 114A. (Note: Formerly Chem. 112A. Students may not receive credit for both Chem. 108 and BIBC 103.) A materials fee may be required for this course. (F,W)

**109. Recombinant DNA Laboratory (6)**
This laboratory will introduce students to the tools of molecular biology and will involve experiments with recombinant DNA techniques. **Prerequisites:** Chem. 143A and, Chem. 114A. (Note: Formerly Chem. 112B. Students may not receive credit for both Chem. 109 and BIMM 101.) A materials fee may be required for this course. (S)

**113. Physical Chemistry of Biological Macromolecules (4)**
(Conjoined with Chem. 213.) A discussion of the physical principles governing biological macromolecular structure and function, and the physicochemical experiments used to probe their structure and function. Chem. 213 students will be required to complete an additional paper and/or exam beyond that expected of students in Chem. 113. **Prerequisites:** Chem. 140C or 140CH; and Chem. 127 or 131 (113); or graduate standing (213).

**114A. Biochemical Structure and Function (4)**
Introduction to biochemistry from a structural and functional viewpoint. **Prerequisite:** Chem. 140A. (Note: Students may not receive credit for both Chem. 114A and BIBC 100.) (F,W)

**114B. Biochemical Energetics and Metabolism (4)**
This course is an introduction to the metabolic reactions in the cell which produce and utilize energy. The course material will include energy-producing pathways: glycolysis, Krebs cycle, oxidative phosphorylation, fatty-acid oxidation. Biosynthesis of amino acids, lipids, carbohydrates, purines, pyrimidines, proteins, nucleic acids. **Prerequisite:** Chem. 114A or BIBC 100. (Note: Students may not receive credit for both Chem. 114B and BIBC 102) (W)

**114C. Biosynthesis of Macromolecules (4)**
Mechanisms of biosynthesis of macromolecules—particularly proteins and nucleic acids. Emphasis is on how these processes are controlled and integrated with metabolism of the cell. **Prerequisite:** Chem. 114A or BIBC 100. (Note: Students may not receive credit for both Chem. 114C and BIMM 100.) (S)

**114D. Molecular and Cellular Biochemistry (4)**
(Conjoined with Chem. 214.) This course represents a continuation of 114C, or an introductory course for first- and second-year graduate students, and covers topics in molecular and cellular biochemistry. Emphasis will be placed on contemporary approaches to the isolation and characterization of mammalian genes and proteins, and molecular genetic approaches to understanding eukaryotic development and human disease. Chem. 214 students will be required to complete additional course work beyond that expected of students in Chem. 114D. **Prerequisites:** Chem. 114A–C or consent of instructor. (May not be offered every year.)

**116. Chemistry of Enzyme Catalyzed Reactions (4)**
A discussion of the chemistry of representative enzyme catalyzed reactions is presented. Enzyme reaction mechanisms and their relation to enzyme structure are emphasized. **Prerequisites:** Chem. 140C or 140CH, and Chem. 114A. (May not be offered every year.)

**118. Pharmacology and Toxicology (4)**
A survey of the biochemical action of drugs and toxins as well as their absorption and excretion. **Prerequisites:** Chem. 140C or 140CH; and Chem. 114A and 114B, or consent of instructor. Priority will be given to Pharmacological Chemistry majors. (S)

**120A. Inorganic Chemistry I (4)**
The chemistry of the main group elements in terms of atomic structure, ionic and covalent bonding. Structural theory involving s, p, and unfilled d orbitals. Thermodynamic and spectroscopic criteria for structure and stability of compounds and chemical reactions of main group elements in terms of molecular structure and reactivity. **Prerequisites:** Chem. 6C or 6CH and Chem. 140A. (F,S)

**120B. Inorganic Chemistry II (4)**
A continuation of the discussion of structure, bonding, and reactivity with emphasis on transition metals and other elements using filled d orbitals to form bonds. Coordination chemistry in terms of valence bond, crystal field, and molecular orbital theory. The properties and reactivities of transition metal complexes including organometallic compounds. **Prerequisite:** Chem. 120A. (W)

**123. Advanced Inorganic Chemistry Laboratory (4)**
Synthesis, analysis, and physical characterization of inorganic chemical compounds. A materials fee is required for this course. **Prerequisites:** Chem. 120A and 143AH or 143A. (W,S)

**124. Bioinorganic Chemistry (4)**
(Conjoined with Chem. 225.) The roles of metal ions in biological systems, with emphasis on transition metal ions in enzymes that transfer electrons, bind oxygen, and fix nitrogen. Also included are metal complexes in medicine, toxicity, and metal ion storage and transport. Chem. 225 students will be required to complete an additional paper and/or exam beyond that expected of students in Chem. 124. **Prerequisite:** Chem. 114A or 120A or graduate standing. (May not be offered every year.)

**126. Physical Chemistry (4)**
An introduction to physical chemistry with emphasis on biochemical and environmental applications. Quantum mechanics and molecular structure, spectroscopy. **Prerequisites:** Phys. 2D, Math. 20D or 21D; or consent of instructor. (W)

**127. Physical Chemistry (4)**
An introduction to physical chemistry with emphasis on biochemical and environmental applications. Thermodynamics, first and second laws, thermochemistry, chemical equilibrium, solutions, kinetic theory, reaction kinetics. **Prerequisite:** Chem. 6C or 6CH, and Math. 20C. (F)

**131. Physical Chemistry (4)**
Thermodynamics, chemical equilibrium, phase equilibrium, chemistry of solutions. **Prerequisites:** Math. 20C or 21C, and Phys. 2B. Recommended: Math. 20D or 21D, and Phys. 2D. (W)

**132. Physical Chemistry (4)**
Chemical statistics, kinetic theory, reaction kinetics. **Prerequisites:** Math. 20D or 21D, Phys. 2B, and Chem. 131. (S)

**133. Physical Chemistry (4)**
Quantum mechanics, atomic and molecular spectroscopy, molecular structure. **Prerequisites:** Chem. 132 and Phys. 2D; or Chem. 6C, Math. 20D or 21D, Math. 20F, and Phys. 2AB; or consent of instructor. (F)

**135. Molecular Spectroscopy (4)**
(Conjoined with Chem. 235.) Time-dependent behavior of systems; interaction of matter with light; selection rules. Radiative and nonradiative processes, coherent phenomena, and the density matrices. Instrumentation, measurement, and interpretation. Chem. 235 students will be required to complete additional course work beyond that expected of students in Chem. 135. **Prerequisites:** Chem. 133 or equivalent; Math. 20D or 21D, or Chem. 190/290. (May not be offered every year.)

**140A. Organic Chemistry I (4)**
Introduction to organic chemistry, with applications to biochemistry. Bonding theory, isomerism, stereochemistry, chemical and physical properties. Introduction to substitution, addition, and elimination reactions. Students may not receive credit for both Chem. 140A and Chem. 141A. **Prerequisite:** Chem. 6C or equivalent course in general chemistry. (F,W,S)

**140B. Organic Chemistry II (4)**
Continuation of Organic Chemistry I, 140A. Methods of analysis, chemistry of hydrocarbons, chemistry of the carbonyl group. Introduction to the reactions of biologically important molecules. Students may not receive credit for both Chem. 141B and Chem. 140B. **Prerequisite:** Chem. 140A (a grade of C or higher in Chem. 140A is strongly recommended). (F,W,S)

**140BH. Honors Organic Chemistry (4)**
Continuation of Organic Chemistry I, Chem. 140A, at honors level. Methods of analysis, chemistry of hydrocarbons, carbonyls, and biologically important molecules. Emphasis on mechanistic aspects of reactions and structure-reactivity relationships. Students may not receive credit for Chem. 140B and Chem. 140BH. **Prerequisite:** Grade of B+ or higher in Chem. 140A.

**140C. Organic Chemistry III (4)**
Continuation of Organic Chemistry I (140A) and Organic Chemistry II (140B). Organic chemistry of biologically important molecules: carboxylic acids, carbohydrates, proteins, fatty acids, biopolymers, natural products. Students may not receive credit for both Chem. 140C and Chem. 141C. **Prerequisite:** Chem. 140B (a grade of C or higher in Chem. 140B is strongly recommended). (F,W,S)

**140CH. Honors Organic Chemistry (4)**
Continuation of Organic Chemistry 140B or 140BH, at honors level. Chemistry of carbonylic acids, carbohydrates, proteins, lipids biopolymers, natural products. Emphasis on mechanistic aspects and structure reactivity relationships. **Prerequisites:** Grade of B+ or higher in Chem. 140B, or B– higher in Chem. 140BH.

**143A. Organic Chemistry Laboratory (4)**
Introduction to organic laboratory techniques. Separation, and purification, spectroscopy, product analysis, and effects of reaction conditions. **Prerequisites:** Chem. 6BL and Chem. 140A or Chem. 141A. A materials fee is required. A mandatory safety exam must be passed within the first two weeks. (**Note:** Students may not receive credit for both Chem. 143A and Chem. 143AH.) (F,W,S)

**143AH. Honors Organic Chemistry Laboratory (4)**
Organic chemistry laboratory for chemistry majors and other honors-level students with strong background in Chem. 140A. Similar to Chem. 143A, but emphasizes instrumental methods of product identification, separation, and analysis. **Prerequisites:** Chem. 6BL and B or better grade in Chem. 140A. A materials fee is required. A mandatory safety exam must be passed within the first two weeks. (**Note:** Students may not receive credit for both Chem. 143A and Chem. 143AH.) (W)

**143B. Organic Chemistry Laboratory (4)**
Continuation of Chem. 143AH or 143A, emphasizing synthetic methods of organic chemistry. **Prerequisites:** Chem. 143AH or 143A, Chem. 140B (may be taken concurrently). Enrollment is limited to majors in the Department of Chemistry and Biochemistry, unless space is available. A materials fee is required for this course. (W,S)

**143C. Organic Chemistry Laboratory (5)**
Identification of unknown organic compounds by a combination of chemical and physical techniques. This course is intended for chemistry majors only. **Prerequisites:** Chem. 6CL or 100A and 143 AH or 143A or equivalent (may be taken concurrently); 143B recommended. A materials fee is required for this course. (F)

**143D. Molecular Design and Synthesis (4)**
Advanced organic synthesis. Relationships between molecular structure and reactivity using modern synthetic methods and advanced instrumentation. Stresses importance of molecular design, optimized reaction conditions for development of practically useful synthesis, and problem-solving skills. **Prerequisites:** Chem. 140C and Chem. 143B. A materials fee is required for this course. (S)

**146. Kinetics and Mechanism of Organic Reactions (4)**
(Conjoined with Chem. 246.) Methodology of mechanistic organic chemistry; integration of rate expression, determination of rate constants, transition state theory; catalysis, kinetic orders, isotope effects, solvent effects, linear free energy relationship; product studies, stereochemistry; reactive intermediates; rapid reactions. Chem. 246 students will be required to complete an additional term project beyond that expected of students in Chem. 146. **Prerequisites:** Chem. 140C or 140CH (146) or graduate standing (246). (May not be offered every year.)

**149A. Environmental Chemistry (4)**
The chemical basis of air and water pollution, chlorofluorocarbons and the ozone hole, the environmental impact of radioactive waste disposal, mineral resource usage, and nuclear energy. **Prerequisite:** Chem. 6C or 6CH or equivalent. (F)

**149B. Environmental Chemistry (4)**
Agricultural productivity, biological impact on the environment, deforestation, environmental disasters (fires, nuclear winter, and volcanoes), and organic waste handling. **Prerequisite:** Chem. 149A. (W)

**151. Molecules that Changed the World (4)**
A look at some of nature's most intriguing molecules and the ability of man to discover, synthesize, modify, and use them. The role of chemistry in society, and how chemical synthesis—the art and science of constructing molecules—shapes our world. **Prerequisite:** Chem. 140A or equivalent.

**152. Synthetic Methods in Organic Chemistry (4)**
(Conjoined with Chem. 252; formerly Chem. 148.) A survey of reactions of particular utility in the organic laboratory. Emphasis is on methods of preparation of carbon-carbon bonds and oxidation reduction sequences. Chem. 252 students will be required to complete an additional paper and/or exam beyond that expected of students enrolled in Chem. 152. **Prerequisite:** Chem. 140C or 140CH (152); or graduate standing (252).

**154. Mechanisms of Organic Reactions (4)**
(Conjoined with Chem. 254; formerly Chem. 147.) A qualitative approach to the mechanisms of various organic reactions; substitutions, additions, eliminations, condensations, rearrangements, oxidations, reductions, free-radical reactions, and photochemistry. Includes considerations of molecular structure and reactivity, synthetic methods, spectroscopic tools, and stereochemistry. The topics emphasized will vary from year to year. This is the first quarter of the advanced organic chemistry sequence. Chem. 254 students will be required to complete an additional paper/exam beyond that expected of students in Chem. 154. **Prerequisite:** Chem. 140C or 140CH (154); or graduate standing (254).

**155. Synthesis of Complex Molecules (4)**
(Conjoined with Chem. 255; formerly Chem. 144.) This course discusses planning economic routes for the synthesis of complex organic molecules. The uses of specific reagents and protecting groups will be outlined as well as the control of stereochemistry during a synthesis. Examples will be selected from the recent literature. Chem. 255 students will be required to complete an additional paper/exam. (May not be offered every year.) **Prerequisite:** Chem. 152 or 252 or consent of instructor.

**156. Structure and Properties of Organic Molecules (4)**
(Conjoined with Chem. 256; formerly Chem. 145.) Introduction to the measurement and theoretical correlation of the physical properties of organic molecules. Topics covered include molecular geometry, molecular-orbital theory, orbital hybridization, aromaticity, chemical reactivity, stereochemistry, infrared and electronic spectra, photochemistry, and nuclear magnetic resonance. Chem. 256 students will be required to complete an additional paper and/or exam beyond that expected of students of Chem. 156. **Prerequisites:** Chem. 140C or 140CH (156); or graduate standing (256).

**157. Bioorganic and Natural Products Chemistry (4)**
(Conjoined with Chem. 257; formerly Chem. 142.) A comprehensive survey of modern bioorganic and natural products chemistry. Topics will include biosynthesis of natural products, molecular recognition, and small molecule-biomolecule interactions. For Chem. 257, students will be required to complete additional course work beyond that expected of students enrolled in Chem. 157. **Prerequisite:** Chem. 140C or 140CH (157); or graduate standing (257).

**158. Applied Spectroscopy (4)**
(Conjoined with Chem. 258.) Intensive coverage of modern spectroscopic techniques used to determine the structure of organic molecules. Problem solving and interpretation of spectra will be strongly emphasized. Chem. 258 students will be required to write and submit a paper that reviews a recent research publication that reports the structure determination by spectroscopic methods of natural products. **Prerequisites:** Chem. 120A and 120B or equivalent.

**161. Supramolecular Coordination Chemistry (4)**
(Conjoined with Chem. 261.) An introduction and survey of modern coordination chemistry. Topics will include structure and bonding of alkali, transition, lanthanide and actinide metals, with emphasis on the first row transition metals; stereochemistry, coordination clusters, molecular solids and nanoparticles. **Prerequisites:** Chem. 120A and 120B or equivalent.

**164. Structural Biology of Viruses (4)**
(Cross-listed with BIMM 164.) An introduction to virus structures, how they are determined, and how they facilitate the various stages of the viral life cycle from host recognition and entry to replication, assembly, release, and transmission to uninfected host cells. (May not be

offered every year.) **Prerequisite:** Chem. 114A or BIBC 100. Recommended preparation: A basic course in cell biology.

**165. 3D Electron Microscopy of Macromolecules (4)**
(Conjoined with Chem. 265; cross-listed with BIMM 162/BGGN 262.) Biological macromolecules and supramolecular complexes as well as organelles, and small cells are being examined in three-dimensions by modern electron cryomicroscopy and image reconstruction techniques. The basic principles of transmission electron microscopy and 3D image reconstruction are discussed. Chem. 265/BGGN 262 students will be required to complete an additional assignment/exam beyond that expected of students in Chem. 165/BIMM 162. **Prerequisites:** Chem. 114A or BIBC 100 or BIBC 110, and Phys. 1A-B-C or Phys. 2A-B-D.

**166. Environmental and Molecular Toxicology (4)**
(Conjoined with Chem. 266.) Molecular and cellular mechanisms underlie the actions of environmental toxicants. This course will investigate approaches to study the impact of environmental toxicants on human health. Other modern approaches that are being implemented to detect and remediate environmental toxicants will also be examined. Chem. 266 students will be required to complete an additional assignment/exam beyond that expected of students in Chem. 166. **Prerequisites:** Chem. 114A–B.

**173. Atmospheric Chemistry (4)**
(Conjoined with Chem. 273.) Chemical principles applied to the study of atmospheres. Atmospheric photochemistry, radical reactions, chemical lifetime determinations, acid rain, greenhouse effects, ozone cycle, and evolution are discussed. Chem. 273 students will be required to complete an additional assignment/exam beyond that expected of students in Chem. 173. **Prerequisites:** Chem. 149A and Chem. 127 or 132 (173); or graduate standing (273). (S)

**174. Chemical Principles of Marine Systems (4)**
(Cross-listed with SIO 141.) Introduction to the chemistry and distribution of the elements in seawater, emphasizing basic chemical principles such as electron structure, chemical bonding, and group and periodic properties and showing how these affect basic aqueous chemistry in marine systems. **Prerequisite:** Chem. 6C with a grade of C– or better, or consent of instructor. (May not be offered every year.)

**182. Biological Databases (4)**
(Cross-listed with BIMM 182/BENG 182/CSE 182.) This course provides an introduction to the features of biological data, how those data are organized efficiently in databases, and how existing data resources can be utilized to solve a variety of biological problems. Object oriented databases, data modeling, and description. Survey of current biological database with respect to above, implementation of database on a biological topic. **Prerequisite:** CSE 100 or Math. 176. Bioinformatics majors only.

**184. Computational Molecular Biology (4)**
(Cross-listed with BIMM 184/BENG 184/CSE 184.) This advanced course covers the application of machine learning and modeling techniques to biological systems. Topics include gene structure, recognition of DNA and protein sequence patterns, classification, and protein structure prediction. Pattern discovery, Hidden Markov models/support vector machines/neural network/profiles, protein structure prediction, functional characterization or proteins, functional genomics/proteomics, metabolic pathways/gene networks. **Prerequisites:** BIMM 181 or BENG 181 or CSE 181; BIMM 182 or BENG 182 or CSE 182 or CHEM 182. Bioinformatics majors only.

**185. Introduction to Computational Chemistry (4)**
(Conjoined with Chem. 285.) Course in computational methods building on a background in mathematics and physical chemistry. Brief introduction and background in computational theory, molecular mechanics, semi-empirical methods, and ab initio-based methods of increasing elaboration. Emphasis on applications and reliability. Chem. 285 students will be required to complete an additional assignment/exam beyond that expected of students in Chem. 185. **Prerequisites:** Chem. 126 or 133 and Math. 20C or 21C. (May not be offered every year.)

**187. Foundations of Teaching and Learning Science (4)**
(Cross-listed with EDS 122.) Examine theories of learning and how they are important in the science classroom. Conceptual development in the individual student, as well as the development of knowledge in the history of science. Key conceptual obstacles in science will be explored. **Prerequisites:** Chem. 6C and Chem. 96.

**188. Capstone Seminar in Science Education (4)**
(Cross-listed with EDS 123.) In the lecture and observation format, students continue to explore the theories of learning in the science classroom. Conceptual development is fostered, as well as continued development of knowledge of science history. Students are exposed to the science of teaching in science in actual practice. **Prerequisites:** Chem. 6C and Chem. 187/EDS 122.

**192. Senior Seminar in Chemistry and Biochemistry (1)**
The Senior Seminar Program is designed to allow senior undergraduates to meet with faculty members in a small group setting to explore an intellectual topic in chemistry or biochemistry. May be taken for credit up to four times, with a change in topic, and permission of the department. **Prerequisites:** department stamp and/or consent of the instructor.

**195. Methods of Teaching Chemistry (4)**
An introduction to teaching chemistry. Students are required to attend a weekly class on methods of teaching chemistry, and will teach a discussion section of one of the lower-division chemistry courses. Attendance at lecture of the lower-division course in which the student is participating is required. (P/NP grades only.) **Prerequisite:** consent of instructor. (F,W,S)

**196. Reading and Research in Chemical Education (2 or 4)**
Independent literature or classroom research by arrangement with, and under the direction of, a member of the Department of Chemistry and Biochemistry faculty. Students must register on a P/NP basis. **Prerequisites:** upper-division standing, 2.5 minimum GPA, consent of instructor and department. (F,W,S)

**199. Reading and Research (2 or 4)**
Independent literature or laboratory research by arrangement with, and under the direction of, a member of the Department of Chemistry and Biochemistry faculty. Students must register on a P/NP basis. **Prerequisites:** upper-division standing, 2.5 minimum GPA, consent of instructor and department. (F,W,S)

## GRADUATE

**204. Introduction to X-ray Crystallography (4)**
(Conjoined with Chem. 104.) Analysis of macromecular structures by X-ray diffraction. Topics include symmetry, geometry of diffraction, detection of diffraction, intensity of diffracted waves, phase problem and its solution, heavy atom method, isomorphous replacement, anomalous dispersion phasing methods (MAD), direct methods, molecular replacement. Chem. 204 students will be required to complete additional paper and/or exam beyond that expected of students in Chem. 104.

**207. Protein NMR (4)**
A broad introduction to the uses of nuclear magnetic resonance to characterize and understand proteins. Not highly mathematical, this course should be accessible to chemistry graduate students working with proteins.

**209. Macromolecular Recognition (4)**
Structures and functions of nucleic acids, folding and catalysis of nucleic acids, motifs and domains of proteins, principles of protein-protein interactions, chemistry of protein/DNA and protein/RNA interfaces, conformational changes in macromolecular recognition. **Prerequisites:** biochemistry background and graduate standing, or approval of instructor.

**211. Metabolic Biochemistry (4)**
A comprehensive course in biochemistry emphasizing metabolic and human biochemistry. **Prerequisites:** physical and organic chemistry; graduate standing. (F)

**213. Physical Chemistry of Biological Macromolecules (4)**
(Conjoined with Chem. 113.) A discussion of the physical principles governing biological macromolecular structure and function, and the physicochemical experiments used to probe their structure and function. Chem. 213 students will be required to complete an additional paper and/or exam beyond that expected of students in Chem. 113. **Prerequisites:** Chem. 140C or 140CH; and Chem. 127 or 131 (113); or graduate standing (213).

**214. Molecular and Cellular Biochemistry (4)**
(Conjoined with Chem. 114D.) This course represents a continuation of 114C, or an introductory course for first- and second-year graduate students, and covers topics in molecular and cellular biochemistry. Emphasis will be placed on contemporary approaches to the isolation and characterization of mammalian genes and proteins, and molecular genetic approaches to understanding eukaryotic development and human disease. Chem. 214 students will be required to complete additional course work beyond that expected of students in Chem. 114D. **Prerequisite:** Chem. 114A–C or consent of instructor. (May not be offered every year.)

**215. Modeling Biological Macromolecules (4)**
(Conjoined with Chem. 115; cross-listed with PHAR 205/BIOM 205.) Use of computer graphics and modeling methods in the study of biological macromolecules. The course will cover basic methods and techniques. The objective is to provide a good working knowledge of the critical features of the methods and to provide a foundation for further study for those who wish to pursue these methods as research topics. Chem. 215/BIOM 205/PHAR 205 students will be required to complete additional course work beyond that expected of students in Chem. 115. **Prerequisite:** Chem. 114A or equivalent. (May not be offered every year.)

**216. Chemical Biology (4)**
A discussion of current topics in chemical biology including mechanistic aspects of enzymes and cofactors, use of modified enzymes to alter biochemical pathways, chemical intervention in cellular processes, and natural product discovery. **Prerequisite:** graduate standing or consent of instructor. (May not be offered every year.)

**219. Special Topics in Biochemistry (4)**
This special topics course is designed for first-year graduate students in biochemistry. Topics presented in recent years have included protein processing, the chemical modification of proteins, the biosynthesis and function of glycoproteins, lipid biochemistry and membrane structure, and bioenergetics. **Prerequisites:** undergraduate courses in biochemistry, Chem. 114A or equivalent. (May not be offered every year.)

**220. Regulatory Circuits in Cells (4)**
Modulation cellular activity and influencing viral fate involve regulatory circuits. Emergent properties include dose response, cross-regulation, dynamic, and stochastic behaviors. This course reviews underlying mechanisms and involves mathematical modeling using personal computer tools.

**221. Signal Transduction (4)**
The aim of this course is to develop an appreciation for a variety of topics in signal transduction. We will discuss several historical developments while the focus will be on current issues. Both experimental approaches and results will be included in our discussions. Topics may vary from year to year. **Prerequisites:** biochemistry and molecular biology. (May not be offered every year.)

**222. Structure and Analysis of Solids (4)**
(Cross-listed with MATS 227.) Key concepts in the atomic structure and bonding of solids such as metals, ceramics, and semiconductors. Symmetry operations, point groups, lattice types, space groups, simple and complex inorganic compounds, structure/property comparisons, structure determination with X-ray diffraction. Ionic, covalent, metallic bonding compared with physical properties. Atomic and molecular orbitals, bands versus bonds, free electron theory.

**224. Spectroscopic Techniques (4)**
Application of physical techniques to the elucidation of the structure of inorganic complex ions and organometallic compounds. Topics covered include group theory, and its application to vibrational, magnetic resonance and Raman spectroscopy. (May not be offered every year.)

**225. Bioinorganic Chemistry (4)**
(Conjoined with Chem. 125.) The role of metal ions in biological systems, with emphasis on transition metal ions in enzymes that transfer electrons, bind oxygen, and fix nitrogen. Also included are metal complexes in medicine, toxicity, and metal ion storage and transport. Chem. 225 students will be required to complete an additional paper and/or exam beyond that expected of students in Chem. 125. **Prerequisite:** Chem. 114A or 120A, or graduate standing. (May not be offered every year.)

**226. Transition Metal Chemistry (4)**
Advanced aspects of structure and bonding in transition metal complexes with major emphasis on Molecular Orbital Theory. Electronic structure descriptions are used to rationalize structure/reactivity relationships. Other topics include computational chemistry, relativistic effects, metal-metal bonding, and reaction mechanisms. **Prerequisite:** Graduate standing or consent of instructor.

**227. Seminar in Inorganic Chemistry (2)**
Seminars presented by faculty and students on topics of current interest in inorganic chemistry, including areas such as bioinorganic, organometallic and physical-inorganic chemistry. The course is designed to promote a critical evaluation of the available data in specialized areas of inorganic chemistry. Each quarter three or four different topics will be discussed. **Prerequisite:** graduate standing or consent of instructor. (S/U grades only.)

**228. Solid State Chemistry (4)**
Survey of the chemistry of semiconductors, superconductors, molecular magnetic materials, zeolites, fast ion conductors, electronically conducting polymers and ceramics. Synethetic techniques such as molecular precursor design, the sol-gel process, electrosynthesis, and high-temperature thermolysis will be covered. (May not be offered every year.)

**229. Special Topics in Inorganic Chemistry (2–4)**
Selection of topics of current interest. May be repeated for credit when topics vary. (May not be offered every year.)

**230A. Quantum Mechanics I (4)**
Theoretical basis of quantum mechanics; postulates; wave packets; matrix representations; ladder operators; exact solutions for bound states in 1, 2, or 3 dimensions; angular momentum; spin; variational approximations; description of real one and two electron systems. Recommended background: Chem. 133 and Math. 20D or their equivalents.

**230B. Quantum Mechanics II (4)**
Continuation of theoretical quantum mechanics: evolution operators and time dependent representations, second quantization, Born-Oppenheimer approximation, electronic structure methods, selected topics from among density operators, quantized radiation fields, path integral methods, scattering theory. Prerequisite: Chem. 230A or consent of instructor.

**231. Chemical Kinetics and Molecular Reaction Dynamics (4)**
Classical kinetics, transition state theory, unimolecular decomposition, potential energy surfaces; scattering processes and photodissociation processes. (May not be offered ever year.)

**232A. Statistical Mechanics I (4)**
Derivation of thermodynamics from atomic descriptions. Ensembles, fluctuations, classical (Boltzmann) and quantum (Fermi-Dirac and Bose-Einstein) statistics, partition functions, phase space, Liouville equation, chemical equilibrium, applications to weakly interacting systems, such as ideal gases, ideal crystals, radiation fields. Recommended background: Chem. 132 or its equivalent. Classical and quantum mechanics, thermodynamics, and mathematical methods will be reviewed as needed, but some background will be necessary.

**232B. Statistical Mechanics II (4)**
Interacting systems at equilibrium, both classical (liquids) and quantum (spins). Phase transitions. Non-equilibrium systems: glasses, transport, time correlation functions, Onsager relations, fluctuation-dissipation theorem, random walks, Brownian motion. Applications in biophysics. **Prerequisite:** Chem. 232A or consent of instructor.

**235. Molecular Spectroscopy (4)**
(Conjoined with Chem. 135.) Time-dependent behavior of systems; interaction of matter with light; selection rules. Radiative and nonradiative processes, coherent phenomena and the density matrices. Instrumentation, measurement, and interpretation. Chem. 235 students will be required to complete additional course work beyond that expected of students in Chem. 135. **Prerequisites:** Chem. 133 or equivalent; Math. 20D or 21D; or Chem. 190/290. (May not be offered every year.)

**239. Special Topics in Chemical Physics (2 or 4)**
Topics of special interest will be presented. Examples include NMR, solid-state chemistry, phase transitions, stochastic processes, scattering theory, nonequilibrium processes, tensor transformations, and advanced topics in statistical mechanics, thermodynamics, and chemical kinetics. (May not be offered every year.)

**240. Electrochemistry (4)**
(Cross-listed with MATS 230.) Application of electrochemical techniques to chemistry research. Basic electrochemical theory and instrumentation: the diffusion equations, controlled potential, and current methods. Electro-chemical kinetics, Butler-Volmer, Marcus-Hush theories, preparative electrochemistry, analytical electrochemistry, solid and polymer electrolytes, semiconductor photoelectrochemistry. (May not be offered every year.)

**246. Kinetics and Mechanism (4)**
Methodology of mechanistic organic chemistry: integration of rate expressions, determination of rate constants, transition state theory; catalysis, kinetic orders, isotope effects, substituent effects, solvent effects, linear free energy relationship; product studies, stereochemistry; reactive intermediates; rapid reactions. (May not be offered every year.)

**250. Seminar in Chemistry (2)**
Regularly scheduled seminars by first-year graduate students provide opportunities for practice in seminar delivery and for the exploration of topics of general interest. (S/U grades only.) (S)

**251. Research Conference (2)**
Group discussion of research activities and progress of the group members. **Prerequisite:** consent of instructor. (S/U grades only.) (F,W,S)

**252. Synthetic Methods in Organic Chemistry (4)**
(Conjoined with Chem. 152; formerly Chem. 248.) A survey of reactions of particular utility in the organic laboratory. Emphasis is on methods of preparation of carbon-carbon bonds and oxidation reduction sequences. For Chem. 252, students would be required to complete an additional paper and/or exam beyond that expected of students enrolled in Chem. 152. **Prerequisite:** Chem. 140C or 140CH (152), or graduate standing (252).

**254. Mechanisms of Organic Reactions (4)**
(Conjoined with Chem. 154; formerly Chem. 247.) A qualitative approach to the mechanisms of various organic reactions; substitutions, additions, eliminations, condensations, rearrangements, oxidations, reductions, free-radical reactions, and photochemistry. Includes considerations of molecular structure and reactivity, synthetic methods, spectroscopic tools, and stereochemistry. The topics emphasized will vary from year to year. This is the first quarter of the advanced organic chemistry sequence. Chem. 254 students will be required to complete an additional paper and/or exam beyond that expected of students in Chem. 154. **Prerequisite:** Chem. 140C or 140CH (154), or graduate standing (254).

**255. Synthesis of Complex Molecules (4)**
(Conjoined with Chem. 155; formerly Chem. 244.) This course discusses planning economic routes for the synthesis of complex organic molecules. The uses of specific reagents and protecting groups will be outlined as well as the control of stereochemistry during a synthesis. Examples will be selected from the recent literature. Chem. 255 students will be required to complete an additional paper and/or exam beyond that expected of students in Chem. 155. (May not be offered every year.) **Prerequisite:** Chem. 152 or 252 or consent of instructor.

**256. Structure and Properties of Organic Molecules (4)**
(Conjoined with Chem. 156; formerly Chem. 245.) Introduction to the measurement and theoretical correlation of the physical properties of organic molecules. Topics covered include molecular geometry, molecular-orbital theory, orbital hybridization, aromaticity, chemical reactivity, stereochemistry, infrared and electronic spectra, photochemistry, and nuclear magnetic resonance. Chem. 256 students will be required to complete an additional paper and/or exam beyond that expected of students in Chem. 156. **Prerequisite:** Chem. 140C or 140CH (156), or graduate standing (256).

**257. Biorganic and Natural Products Chemistry (4)**
(Conjoined with Chem. 157; formerly Chem. 242.) A comprehensive survey of modern bioorganic and natural products chemistry. Topics include biosynthesis of natural products, molecular recognition, and small molecule-biomolecule interactions. Chem. 257 students will be required to complete additional course work beyond that expected of students in Chem. 157. **Prerequisite:** Chem. 140C or 140CH (157), or graduate standing (257).

**258. Applied Spectroscopy (4)**
(Conjoined with Chem. 158.) Intensive coverage of modern spectroscopic techniques used to determine the structure of organic molecules. Problem solving and interpretation of spectra will be strongly emphasized. Chem. 258 students will be required to write and submit a paper that reviews a recent research publication that reports the structure determination by spectroscopic methods of natural products. **Prerequisite:** Chem. 154 or 254 or consent of instructor.

**259. Special Topics in Organic Chemistry (2–4)**
(Formerly Chem. 249.) Various advanced topics in organic chemistry. Includes but is not limited to: advanced kinetics, advanced spectroscopy, computational chemistry, heterocyclic chemistry, medicinal chemistry, organotransition metal chemistry, polymers, solid-phase synthesis/combinatorial chemistry, stereochemistry, and total synthesis classics.

**260. Light and Electron Microscopy of Cells and Tissue (4)**
Students will review basic principles of light and electron microscopy and learn a variety of basic and advanced microscopy methods through lecture and hands-on training. Each student will have his or her own project. Additional supervised instrument time is available. **Prerequisite:** consent of instructor.

**261. Supramolecular Coordination Chemistry (4)**
(Conjoined with Chem. 161.) An introduction and survey of modern coordination chemistry. Topics will include structure and bonding of alkali, transition, lanthanide, and actinide metals, with emphasis on the first row transition metals; stereochemistry, coordination clusters, molecular solids and nanoparticles. Chem. 261 students will be required to complete additional course work beyond that expected of students in Chem. 161. **Prerequisites:** Chem. 120A, 120B or equivalent; or graduate standing.

**262. Inorganic Chemistry and NMR (4)**
A survey of inorganic chemistry to prepare for graduate research in the field, including a detailed introduction to nuclear magnetic resonance (NMR), followed by applications of NMR to structural and mechanistic problems in inorganic chemistry.

**264. Structural Biology of Viruses (4)**
(Cross-listed with BGGN 264.) An introduction of virus structures, how they are determined, and how they facilitate the various stages of the viral life cycle from host recognition and entry to replication, assembly, release, and transmission to uninfected host cells. Students will be required to complete a term paper. (May not be offered every year.) Recommended: Elementary biochemistry as treated in

Chem. 114A or BIBC 100 and a basic course in cell biology or consent of the instructor.

**265. 3D Electron Microscopy of Macromolecules (4)**
(Cross-listed with BGGN 262.) Biological macromolecules and supramolecular complexes as well as organelles, and small cells are being examined in three-dimensions by modern electron cryomicroscopy and image reconstruction techniques. The basic principles of transmission electron microscopy and 3D image reconstruction are discussed. Chem. 265/BGGN 262 students will be required to complete an additional oral presentation or paper or exam beyond that expected of students in Chem. 165/BGGN 162. (May not be offered every year.) Recommended: Elementary biochemistry as treated in Chem. 114A or BIBC 100 and a basic course in cell biology or consent of instructor.

**266. Environmental and Molecular Toxicology (4)**
(Conjoined with Chem. 166; cross-listed with BIMM 166/BGGN 256/BIOM 266.) Molecular and cellular mechanisms underlie the actions of environmental toxicants. This course will investigate approaches to study the impact of environmental toxicants on human health. Other modern approaches that are being implemented to detect and remediate environmental toxicants will also be examined. Chem. 266 students will be required to complete an additional paper and/or exam beyond that expected of students in Chem. 166. (W)

**270A-B-C. Current Topics in Environmental Chemistry (2-2-2)**
Seminar series on the current topics in the field of environmental chemistry. Emphasis is on current research topics in atmospheric, oceanic, and geological environments. **Prerequisite:** consent of instructor. (S/U grades only.) (May not be offered every year.)

**271. Special Topics in Analytical Chemistry (4)**
Topics of special interest in analytical chemistry. May include, but is not limited to, chemical separation, sample introductions, mass analyzers, ionization schemes, and current state-of-the-art applications in environmental and biological chemistry.

**273. Atmospheric Chemistry (4)**
(Conjoined with Chem. 173.) Chemical principles applied to the study of atmospheres. Atmospheric photochemistry, radical reactions, chemical lifetime determinations, acid rain, greenhouse effects, ozone cycle, and evolution are discussed. Chem. 273 students will be required to complete additional assignment/exam beyond that expected of students in Chem. 173. **Prerequisites:** Chem. 149A and Chem. 127 or 132 (173), or graduate standing (273). (S)

**276. Numerical Analysis in Multiscale Biology (4)**
Introduces mathematical tools to simulate biological processes at multiple scales. Numerical methods for ordinary and partial differential equations (deterministic and stochastic), and methods for parallel computing and visualization. Hands-on use of computers emphasized; students will apply numerical methods in individual projects. **Prerequisite:** consent of instructor. (S)

**280. Applied Bioinformatics (4)**
Publicly available databases and bioinformatics tools are now an indispensable component of biomedical research. This course offers an introductory survey of selected tools and databases; the underlying concepts, the software, and advice on using them. Practical exercises will be included.

**283. Supramolecular Structure Determination Laboratory (4)**
A laboratory course combining hands-on mass spectrometry and bioinformatics tools to explore the relationship between structure and function in macromolecules. Tools for peptide sequencing, analysis of post-translational modification, and fragmentation analysis by mass spectrometry are examples of experiments students will run. **Prerequisite:** consent of instructor.

**285. Introduction to Computational Chemistry (4)**
(Conjoined with Chem. 185.) Course in computational methods building on a background in mathematics and physical chemistry. Brief introduction and background in computational theory, molecular mechanics, semi-empirical methods, and ab initio-based methods of increasing elaboration. Emphasis on applications and reliability. Chem. 285 students will be required to complete an additional paper and/or exam beyond that expected of students in Chem. 185. **Prerequisites:** Chem. 126 or 133 and Math. 20C. (May not be offered every year.)

**288. Algorithms in Contemporary Computational Biology (4)**
Course will focus on several topics in contemporary computational biology, including inference of gene modules, reconstructing gene regulatory network, and predicting signal transduction network. Algorithms that will be discussed include Bayesian network, hidden Markov model, and Markov chain Monte Carlo. Recommended preparation: Chem. 184 and basic concepts of probability, statistics. and molecular biology.

**294. Organic Chemistry Seminar (2)**
Formal seminars or informal puzzle sessions on topics of current interest in organic chemistry, as presented by visiting lecturers, local researchers, or students. **Prerequisite:** advanced graduate-student standing. (S/U grades only.) (F,W,S)

**295. Biochemistry Seminar (2)**
Formal seminars or informal puzzle sessions on topics of current interest in biochemistry, as presented by visiting lecturers, local researchers, or students. **Prerequisite:** advanced graduate-student standing. (S/U grades only.)

**296. Chemical Physics Seminar (2)**
Formal seminars or informal sessions on topics of current interest in chemical physics as presented by visiting lecturers, local researchers, or students. **Prerequisite:** advanced graduate-student standing. (S/U grades only.) (F,W,S)

**297. Experimental Methods in Chemistry (4)**
Experimental methods and techniques involved in chemical research are introduced. Hands-on experience provides training for careers in industrial research and for future thesis research. **Prerequisite:** graduate-student standing. (S/U grades only.)

**298. Special Study in Chemistry (1–4)**
Reading and laboratory study of special topics for first-year graduate students under the direction of a faculty member. Exact subject matter to be arranged in individual cases. (S/U grades only.) **Prerequisite:** first-year graduate-student standing. (F,W,S)

**299. Research in Chemistry (1–12)**
**Prerequisites:** graduate-student standing and consent of instructor. (S/U grades only.) (F,W,S)

**500. Teaching in Chemistry (4)**
A doctoral student in chemistry is required to assist in teaching undergraduate chemistry courses. One meeting per week with instructor, one or more meetings per week with assigned class sections or laboratories, and attendance at the lecture of the undergraduate course in which he or she is participating. **Prerequisites:** graduate-student standing and consent of instructor. (S/U grades only.) (F,W,S)