Department of Chemistry

Linda Peteanu, Department Head
Keith H. Stump, Director of Undergraduate Studies
Office: Doherty Hall 1316
http://www.chem.cmu.edu

Chemistry at Carnegie Mellon University is a shared mission to advance energy and sustainability solutions and to improve human health by generating, exploring, and harnessing new molecular design paradigms. Chemistry is an area of science involved with the study of the properties and reactions of substances ranging from living cells to subatomic particles. It is at the center of many sciences and technical fields, providing the fundamental knowledge and tools needed to address many of society’s needs and to explore the unknown. Fields as diverse as genetic engineering, materials science and nanotechnology look to chemistry when they look to the future, for that is where the ultimate in understanding — the molecular level — resides.

The chemistry profession is extraordinarily diverse, with career opportunities available in the chemical, petroleum, renewable energy, nuclear power, novel polymeric materials, metals, and pharmaceutical industries, among many others. Chemistry plays an increasingly important role in the rapidly expanding biotechnology industry. In addition to careers in industry and academia, many chemists find challenging careers in the public sector in the laboratories of the National Institutes of Health, the Department of Agriculture, the Environmental Protection Agency, the National Institute of Standards and Technology, and the Department of Energy as well as in consulting. Chemistry alums also find employment in technical fields unrelated to science where their problem solving and communication skills are highly valued.

Chemistry is a particularly suitable major for pre-medical and other pre-health profession students. Medical schools look favorably on the rigorous reasoning skills chemists develop, as evidenced by an excellent record for student admission to advanced education in these areas. An increasing number of our graduates are seeking careers in dentistry, pharmacy or pharmacology. The Health Professions Program advises all Carnegie Mellon students considering careers in health fields. (See Health Professions Program description in this catalog for more information.) Chemistry is particularly attractive to pre-law majors anticipating a career in a legal department in the chemical industry, in patent, intellectual property or environmental law. Students interested in industrial careers often combine their chemistry program with undergraduate courses in business administration or eventually go on to study for an M.B.A.

The Department offers three Bachelor’s degrees: the B.S. in Chemistry, The B.S. in Chemistry/Biological Chemistry Track and the B.A. in Chemistry. One of the unique features of the B.A. degree is the freedom for the student to tailor the program by taking any of the departments of the University and therefore offers a high degree of flexibility. For the B.S. degrees, electives are often technical courses in chemistry or related fields of science, technology and engineering, such as biology, physics, mathematics, chemical, biomedical or materials science engineering or computer science, although they can be in other non-technical areas as well. It is possible to have all of the technical requirements completed after the junior year in the B.S. and B.A. degree programs, allowing students the flexibility to combine electives in the senior year into a focused program of specialization or to allow for additional breadth in their undergraduate experience. Students interested in graduate studies in chemistry may enroll in graduate courses. Those desiring immediate job placement may be interested in one or more of the formal options that supplement the chemistry B.S. degree.

These are described in detail later in this section of the catalog. Carnegie Mellon has one of the strongest polymer science programs in the world and the undergraduate polymer science, materials chemistry or polymers and sciences options offer training that is particularly valuable for an industrial career. The Computational Chemistry option provides students with expertise in scientific computing that is highly sought after by employers in the pharmaceutical industry.

The overlap between the fields of chemistry and biological sciences continues to grow, with increased emphasis on synthetic chemicals that are used as probes or reporters of biological function and diagnostic and/or therapeutic agents. In addition, the application of sophisticated spectroscopic, structural and scanning probe/force methods on scales as low as single molecules is driving innovation and education at the chemistry/biology interface. Based on these trends the department offers the B.S. in Chemistry/Biological Chemistry Track to better prepare students for advanced studies and a job market that values knowledge and skills from both disciplines. A combination of advanced research-focused lecture coursework offerings and a new laboratory course allows students to build the strong foundation typical of a successful chemistry major, while expanding out into applications of chemistry in the biological sciences. Students who complete the track will have been exposed to the latest research accomplishments and unanswered questions in biological chemistry while also gaining experience in experimental methods unique to research at this interface.

An honors program is offered for highly motivated undergraduates. It is designed primarily for students who wish to undertake a strong research-intensive program of study in contemporary chemistry. The program B.S. in Chemistry with Departmental Honors requires the completion of at least one graduate level course in chemistry, a research project, and the writing and defense of a bachelor’s level honors thesis. An advanced track leading to the B.S. in Chemistry with Departmental Honors together with a Masters Degree in Chemistry involves completion of five graduate level courses and a more extensive thesis research project. This degree path is especially attractive to students who plan to pursue an industrial career. With enough advanced placement credit or by carrying heavier than usual course loads, students can complete the Honors/M.S. degree program in 8 semesters. The majority of openings in the chemical industry presently are at the Bachelors and Masters degree levels.

Additional majors (double majors) are available with nearly all other departments in the university provided the student can fit the required courses into the schedule. Generally, all the requirements for both departments must be met for an additional major (except for some courses with similar content). Programs are also available that lead to the degree B.S. in Chemistry with a minor in another discipline such as biological sciences, physics, mathematics, computer science, engineering studies, business administration and certain departments in the Dietrich College of Humanities and Social Sciences. Requirements for most minor programs are described by individual departments in this catalog. However, it is recommended that students who are interested in pursuing a minor as part of their degree consult with the department involved for the current requirements and further guidance about scheduling. Dual degree programs are available in which students receive two separate undergraduate degrees from two different departments in the University. These require students to complete at least 90 units of work per additional degree in addition to the units required for the first degree and the core curriculum from both colleges if the programs are in different units. Several five-year programs have been developed to allow a Carnegie Mellon undergraduate student to earn both a B.S. in Chemistry and a Master of Science degree in fields such as Health Care Policy and Management, Materials Science Engineering or Biomedical Engineering.

Study abroad programs are available for chemistry majors and programs of one to two semesters can generally be accommodated without delaying time to graduation beyond 8 semesters. One example of a formal exchange program is spending two semesters at École Polytechnique Fédérale de Lausanne (EPFL) in Switzerland. Study abroad is encouraged by the chemistry department and also can be arranged on an individual basis at universities throughout the world including Europe, Asia, Africa, New Zealand, and Australia during the academic year, the summer and winter or spring breaks. Students interested in study abroad should consult with their chemistry department and also can be arranged on an individual basis.

One example of a formal exchange program is spending two semesters at École Polytechnique Fédérale de Lausanne (EPFL) in Switzerland. Study abroad is encouraged by the chemistry department and also can be arranged on an individual basis at universities throughout the world including Europe, Asia, Africa, New Zealand, and Australia during the academic year, the summer and winter or spring breaks. Students interested in study abroad should consult with their chemistry department and also can be arranged on an individual basis.

One of the most attractive features of the Department of Chemistry is the opportunity for students to interact with prominent research scientists in entry-level as well as advanced courses and in research. Since the spring of 2003, undergraduate laboratory instruction takes place in a state-of-the-art facility located in Doherty Hall. Participation in undergraduate research is encouraged and qualified students may begin projects as early as their second year. Chemistry majors interested in beginning research should consult with the Director of Undergraduate Studies to begin the process of identifying a research mentor. Approximately 90 to 98% of the graduating chemistry majors during the past ten years have taken part in research either for pay or for credit as part of their undergraduate training. Chemistry majors have been very successful in obtaining Small Undergraduate Research Grants (SURG) and Summer Undergraduate Research Fellowships (SURF) from the University to help support their research projects. Undergraduate and research laboratories are equipped with the latest scientific instrumentation. The use of computational tools is emphasized throughout the curriculum.

Program Outcomes

The faculty members of the Department of Chemistry have approved the following as a statement of our learning outcomes for recipients of an undergraduate degree in chemistry.

Upon graduation recipients of the BS or BA degree in Chemistry will:

Foundational knowledge/theory

- Have a firm foundation in the quantitative and computational thinking that underlies chemistry, including use of modern computational tools.
• Have a firm foundation in the theories and models that form the basis for reasoning about molecular systems.
• Understand how the different subdisciplines of chemistry relate to and complement one another.
• Be able to apply chemical reasoning across disciplines, such as biology, environmental science, materials science, nanotechnology, and engineering.

Practical/Experimental
• Understand that chemistry is fundamentally an experimental science, and be able to identify or create an appropriate model, formulate a hypothesis, choose an appropriate set of tools and techniques, and design an experiment that tests the hypothesis and analyze the results from that experiment drawing sound scientific conclusions from the results obtained.
• Be proficient in the use of both classical and modern tools for analysis of chemical systems.
• Be able to design and carry out synthesis of both organic and inorganic systems.
• Be able to use experience and knowledge gained through theoretical and practical design projects to conduct further research.
• Know and follow the proper procedures and regulations for safe handling and use of chemicals and chemical equipment.

Communication
• Be able to convey information, both orally and in writing, to a range of audience levels and for a variety of purposes.
• Understand how scientific information is shared between peers in modern science, including responsible conduct for acknowledging prior and current contributions.
• Be able to locate, identify, understand and critically evaluate the chemical literature.
• Develop the interpersonal skills to function cooperatively in a team setting.

Society and ethics
• Understand the opportunities and consequences of chemistry for the environment and society for both the short term and for long-term sustainability.
• Understand and apply ethics and values to all professional activities.

Professional development
• Develop an understanding of career opportunities both within and outside of chemistry, including through contacts with faculty, the career and professional development center and alumni.
• Be prepared to pursue a life and career that builds on their experiences at Carnegie Mellon to achieve their personal goals and to contribute positively to society.

B.S. in Chemistry
The majority of undergraduate degrees awarded by the Department of Chemistry are Bachelor of Science degrees. This degree program provides the most appropriate preparation for further graduate study and for industrial positions in research and development or analytical chemistry. The curriculum provides a strong foundation in the fundamental areas of study in chemistry; organic, physical, inorganic and analytical chemistry, along with a rich set of research-focused, instrumentation intensive laboratory experiences aligned with those areas. Students interested in less technical areas of employment or graduate study in areas such as business, policy or law may find the Bachelor of Arts degree a more suitable alternative.

Curriculum - B.S. in Chemistry and Requirements for an Additional Major in Chemistry
This catalog and the sample schedules presented are intended to be used by students in the first year class entering in the fall of 2017 or later. Upperclass students should refer to the appropriate previous version of the catalog published during their first year for the requirements that are specific to them.

The technical breadth requirement of the MCS core curriculum requires a minimum of four technical courses outside of the student’s primary major.

Chemistry majors must at minimum take the following non-chemistry technical courses:

<table>
<thead>
<tr>
<th>Technical Breadth Requirements</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>33-121 Physics I for Science Students</td>
<td>12</td>
</tr>
<tr>
<td>33-122 Physics II for Biological Sciences &amp; Chemistry Students</td>
<td>9</td>
</tr>
<tr>
<td>03-121 Modern Biology or 03-231 Biochemistry I or 03-232 Biochemistry I</td>
<td>9</td>
</tr>
<tr>
<td>15-110 Principles of Computing - or other approved programming course or 15-112 Fundamentals of Programming and Computer Science or 02-201 Programming for Scientists</td>
<td>10</td>
</tr>
<tr>
<td>21-120 Differential and Integral Calculus</td>
<td>10</td>
</tr>
<tr>
<td>21-122 Integration and Approximation</td>
<td>10</td>
</tr>
<tr>
<td>or 21-124 Calculus II for Biologists and Chemists</td>
<td></td>
</tr>
</tbody>
</table>

Students should complete this technical core as early as possible and preferably by the end of their fifth semester.

The non-technical breadth requirements for MCS students include 76-101 Interpretation and Argument, four courses with a minimum of 36 units from the arts, humanities or social sciences and a course of at least 9 units from an approved list in the category of Cultural/Global understanding, three ENGAGE in Wellness courses, 38-230 ENGAGE in Wellness: Looking Inward, 38-330 ENGAGE in Wellness: Looking Outward and 38-430 ENGAGE in Wellness: Looking Forward, 38-110 ENGAGE in Service, 38-220 ENGAGE in the Arts, 38-101 EUREKA! Discovery and Its Impact, the MCS first-year seminar, and 38-301 PROPEL for a total of 72 units. For more information on allowed courses in the arts, humanities and social sciences and electives in the Cultural/Global Understanding category refer to the MCS section of this catalog.

SHS students have their own core education requirements. Please refer to the Intercollege Programs section of this catalog for the SHS requirements. Requests for exceptions within the SHS core must be made to the Director of the SHS program.

Freshman Year

<table>
<thead>
<tr>
<th>Fall</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>09-105 Introduction to Modern Chemistry I or 09-107 Honors Chemistry: Fundamentals, Concepts and Applications</td>
<td>10</td>
</tr>
<tr>
<td>21-120 Differential and Integral Calculus</td>
<td>10</td>
</tr>
<tr>
<td>33-121 Physics I for Science Students</td>
<td>12</td>
</tr>
<tr>
<td>76-101 Interpretation and Argument</td>
<td>9</td>
</tr>
<tr>
<td>38-101 EUREKA! Discovery and Its Impact</td>
<td>6</td>
</tr>
<tr>
<td>99-101 Computing @ Carnegie Mellon</td>
<td>3</td>
</tr>
</tbody>
</table>

50

Students interested in majoring in chemistry who have a strong chemistry background, should enroll in 09-107 rather than 09-105. Students who complete 09-107 with an A grade will be exempted from the requirement to take 09-106 Modern Chemistry II.

02-201 Programming for Scientists is an acceptable alternative to 15-110 for chemistry majors as are any upper level courses in programming.

There are some elective laboratory courses offered for MCS students in the first year. These include 03-115 Phage Genomics Research and 09-122 Modern Biology. There are some elective laboratory courses offered for MCS students in the first year. These include 03-115 Phage Genomics Research and 09-122 Modern Biology. There are some elective laboratory courses offered for MCS students in the first year. These include 03-115 Phage Genomics Research and 09-122 Modern Biology. There are some elective laboratory courses offered for MCS students in the first year. These include 03-115 Phage Genomics Research and 09-122 Modern Biology. There are some elective laboratory courses offered for MCS students in the first year. These include 03-115 Phage Genomics Research and 09-122 Modern Biology.

Spring

<table>
<thead>
<tr>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>09-106 Modern Chemistry II</td>
</tr>
<tr>
<td>Chemistry majors who place out of 09-106 can take 09-348 Inorganic Chemistry, 09-510 Chemistry and Sustainability as a chemistry elective or inquire about the availability of a research placement.</td>
</tr>
<tr>
<td>21-122 Integration and Approximation or 21-124 Calculus II for Biologists and Chemists</td>
</tr>
<tr>
<td>33-121 Physics I for Science Students</td>
</tr>
<tr>
<td>or 03-121 Modern Biology or 15-110 Principles of Computing</td>
</tr>
<tr>
<td>xx-xxx Arts, Humanities and Social Sciences Course</td>
</tr>
</tbody>
</table>
### Sophomore Year

<table>
<thead>
<tr>
<th>Term</th>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>Undergraduate Seminar I</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Modern Organic Chemistry</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Laboratory I: Introduction to Chemical Analysis</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Physics II for Biological Sciences &amp; Chemistry Students</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Course is a prerequisite for 09-331, normally taken in the spring of the junior year</td>
<td></td>
</tr>
<tr>
<td>xx-xxx</td>
<td>Arts, Humanities and Social Sciences Course 2</td>
<td>9</td>
</tr>
</tbody>
</table>

### Junior Year

<table>
<thead>
<tr>
<th>Term</th>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>Undergraduate Seminar III</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Mathematical Methods for Chemists</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Laboratory III: Molecular Design and Synthesis</td>
<td>12</td>
</tr>
<tr>
<td>or 09-323</td>
<td>Biorganic Chemistry Laboratory</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Physical Chemistry (Quantum): Microscopic Principles of Physical Chemistry</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>ENGAGE in Wellness: Looking Inward</td>
<td>1</td>
</tr>
<tr>
<td>xx-xxx</td>
<td>Arts, Humanities and Social Sciences course 4</td>
<td>9</td>
</tr>
</tbody>
</table>

### Senior Year

<table>
<thead>
<tr>
<th>Term</th>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>Undergraduate Seminar V</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Chemistry Elective (see notes on electives)</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>ENGAGE in Service</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>ENGAGE in Wellness: Looking Forward</td>
<td>1</td>
</tr>
<tr>
<td>xx-xxx</td>
<td>Free Electives</td>
<td>30</td>
</tr>
</tbody>
</table>

### Distribution of Units for the B.S. in Chemistry and Requirements for An Additional Major in Chemistry

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>09-105</td>
<td>Introduction to Modern Chemistry I</td>
</tr>
<tr>
<td>09-106</td>
<td>Modern Chemistry II</td>
</tr>
<tr>
<td>09-204</td>
<td>Professional Communication Skills in Chemistry</td>
</tr>
<tr>
<td>09-219</td>
<td>Modern Organic Chemistry</td>
</tr>
<tr>
<td>09-220</td>
<td>Modern Organic Chemistry II</td>
</tr>
<tr>
<td>09-231</td>
<td>Mathematical Methods for Chemists</td>
</tr>
<tr>
<td>09-331</td>
<td>Modern Analytical Instrumentation</td>
</tr>
<tr>
<td>09-344</td>
<td>Physical Chemistry (Quantum): Microscopic Principles of Physical Chemistry</td>
</tr>
<tr>
<td>09-345</td>
<td>Physical Chemistry (Thermo): Macroscopic Principles of Physical Chemistry</td>
</tr>
<tr>
<td>09-348</td>
<td>Inorganic Chemistry</td>
</tr>
<tr>
<td>09-221</td>
<td>Laboratory I: Introduction to Chemical Analysis</td>
</tr>
<tr>
<td>09-222</td>
<td>Laboratory II: Organic Synthesis and Analysis</td>
</tr>
<tr>
<td>09-321</td>
<td>Laboratory III: Molecular Design and Synthesis</td>
</tr>
<tr>
<td>or 09-323</td>
<td>Bioorganic Chemistry Laboratory</td>
</tr>
<tr>
<td>09-342</td>
<td>Laboratory IV: Molecular Spectroscopy and Dynamics</td>
</tr>
<tr>
<td>09-xxx</td>
<td>Chemistry Seminars</td>
</tr>
<tr>
<td>09-xxx</td>
<td>Chemistry Electives</td>
</tr>
</tbody>
</table>

* These, plus 33-121 Physics I for Science Students and 33-122 Physics II for Biological Sciences & Chemistry Students, are the required courses for students earning an additional major in chemistry.

Students who transfer into the department and have taken 09-217 Organic Chemistry I and/or 09-218 Organic Chemistry II, will be required to complete units of 09-435 Independent Study Chemistry, 1 unit per course, under the supervision of the instructor(s) for 09-219 and/or 09-220 in order to master the course content missed in this course sequence.

Students who transfer into the department and have taken 09-207 Techniques in Quantitative Analysis and/or 09-208 Techniques for Organic Synthesis and Analysis will be required to take a 3 unit transition course (09-217 Chemistry Tech I to Lab I Transition for 09-207 and/or 09-216 Chemistry Tech II to Lab II Transition for 09-208) to fulfill the major requirements for 09-221 and/or 09-222.

Chemistry courses required for the BS degree and the additional major in chemistry that are numbered 09-2xx or higher must be taken at Carnegie Mellon University. Exceptions must be requested of and approved by the Director of Undergraduate Studies. In general such requests will be approved only under unusual or extenuating circumstances.

### Other Requirements

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biology (Modern Biology or Biochemistry)</td>
<td>9</td>
</tr>
<tr>
<td>Computer Science</td>
<td>10</td>
</tr>
<tr>
<td>Mathematics</td>
<td>20</td>
</tr>
<tr>
<td>Physics</td>
<td>21</td>
</tr>
<tr>
<td>Interpretation and Argument</td>
<td>9</td>
</tr>
<tr>
<td>Arts, Humanities and Social Sciences Courses</td>
<td>36</td>
</tr>
<tr>
<td>Cultural/Global Understanding</td>
<td>9</td>
</tr>
<tr>
<td>EUREKA! (First-year seminar)</td>
<td>6</td>
</tr>
<tr>
<td>MCS Junior Seminar</td>
<td>6</td>
</tr>
<tr>
<td>ENGAGE in Service</td>
<td>1</td>
</tr>
<tr>
<td>ENGAGE in Wellness Courses (three courses)</td>
<td>3</td>
</tr>
<tr>
<td>ENGAGE in the Arts</td>
<td>2</td>
</tr>
<tr>
<td>Computing @ Carnegie Mellon</td>
<td>3</td>
</tr>
<tr>
<td>Free Electives</td>
<td>62</td>
</tr>
</tbody>
</table>
Minimum number of units required for the degree:

The above B.S. curriculum recommends a range of 41-50 units per semester to meet the minimum degree requirement of 360 units. Students are strongly encouraged to take extra elective courses (except in the first year) in whatever subjects they wish in order to enrich their backgrounds and enhance their educational experience.

Notes on Electives

Chemistry Electives

A minimum of 18 units of chemical electives is required.

Chemistry electives can be satisfied by 09-445 Undergraduate Research, or by most other chemistry courses 09-3xx or higher, undergraduate or graduate level, for which the student has the necessary prerequisites, or by 03-231/03-232 Biochemistry. Biochemistry also fulfills the Life Sciences requirement for the MCS technical breadth requirement. 09-435 Independent Study Chemistry may only be used to fulfill this requirement with permission of the Director of Undergraduate Studies. Certain interdisciplinary courses (e.g. 39-xxx) relating to chemistry can also be used with the approval of the Director of Undergraduate Studies. The scheduling of these electives can vary and students should check with the department offering the course to see which courses are offered in any given year or semester and with the Director of Undergraduate Studies in the Department of Chemistry to ascertain whether the course is an acceptable chemistry elective.

Free Electives

Free electives are defined as including any course offered by Carnegie Mellon except those in science or engineering fields that are primarily intended for non-majors. A maximum of 9 units total of Physical Education, StuCo and/or ROTC courses combined can be counted as free elective units. The Chemistry Department does not require technical electives.

B.A. in Chemistry

The curriculum for the B.A. degree provides students with the opportunity to take a substantial number of elective and non-technical courses. Certain chemistry, math, and other technical courses required for the B.S. degree are replaced by free electives, making this degree an ideal choice for those who wish to earn an additional major with one of the departments in the College of Humanities and Social Sciences, College of Fine Arts, or with the Business Administration program, though this is not a requirement. It is also attractive for students wishing to pursue careers in dentistry or pharmacy, career paths that require a broader preparation at the undergraduate level and hence more coursework outside of chemistry. Students may earn one or more of the options as described for B.S. degree candidates, providing they complete the courses listed.

The suggested curriculum recommends that the required technical courses be completed at the earliest opportunity, however students have considerable flexibility to postpone these courses in favor of electives, allowing compatibility with the programs of other departments. In designing such programs for a minor or additional major with chemistry, students should note that certain required chemistry courses only are offered in specific semesters, not both. These include the Fall-only courses 09-214 Physical Chemistry, 09-219 Modern Organic Chemistry, 09-321 Laboratory III: Molecular Design and Synthesis and 09-323 Bioorganic Chemistry Laboratory and the Spring-only courses 09-220 Modern Organic Chemistry II, 09-348 Inorganic Chemistry, and 09-204 Professional Communication Skills in Chemistry. Also, in some cases, a course that is normally scheduled for the fall may be changed to a spring course (or the inverse) due to a departmental curriculum change.

Curriculum - B.A. in Chemistry

This catalog and the sample schedules presented are intended to be used by students in the first year class entering in the fall of 2017. Upperclass students should refer to the appropriate previous version of the catalog published during their first year for the requirements that are specific to them.

The technical breadth requirement of the MCS core curriculum requires a minimum of four technical courses outside of the student’s primary major. Chemistry majors must at minimum take the following non-chemistry technical courses:

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<thead>
<tr>
<th>Technical Breadth Requirements</th>
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</tr>
<tr>
<td>xx-xx Free Elective</td>
<td>9</td>
</tr>
</tbody>
</table>

Students should complete this technical core as early as possible and preferably by the end of their fifth semester.

The non-technical breadth requirements for MCS students includes 76-101 Interpretation and Argument, four courses with a minimum of 36 units from the arts, humanities or social sciences and a course of at least 9 units from an approved list in the category of Cultural/Global understanding, three ENGAGE in Wellness courses, 38-230 ENGAGE in Wellness: Looking Inward, 38-330 ENGAGE in Wellness: Looking Outward and 38-430 ENGAGE in Wellness: Looking Forward, 38-110 ENGAGE in Service , 38-220 ENGAGE in the Arts, 38-101 EUREKA!: Discovery and its Impact , the MCS first-year seminar, and 38-301 PROPEL for a total of 72 units. For more information on allowed courses in the arts, humanities and social sciences and electives in the Cultural/Global Understanding category refer to the MCS section of this catalog.

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Requests for exceptions within the SHS core must be made to the Director of the SHS program.

First Year

<table>
<thead>
<tr>
<th>Fall</th>
<th>Units</th>
</tr>
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<tbody>
<tr>
<td>09-105 Introduction to Modern Chemistry I or 09-107 Honors Chemistry: Fundamentals, Concepts and Applications</td>
<td>10</td>
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<tr>
<td>21-120 Differential and Integral Calculus</td>
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</tr>
<tr>
<td>38-101 EUREKA!: Discovery and its Impact</td>
<td>6</td>
</tr>
<tr>
<td>99-101 Computing @ Carnegie Mellon</td>
<td>3</td>
</tr>
</tbody>
</table>

50

Students interested in majoring in chemistry who have a strong chemistry background, should enroll in 09-107 rather than 09-105. Students who complete 09-107 with an A grade will be exempted from the requirement to take 09-106 Modern Chemistry II.

02-201 Programming for Scientists is an acceptable alternative to 15-110 for chemistry majors as are any upper level courses in programming.

There are some elective laboratory courses offered for MCS students in the first year. These include 03-115 Phase Genomics Research and 09-122 Molecular Tools for Biological and Chemical Studies. The maximum units allowed during the first semester is 54; therefore, students wishing to take a lab should take an alternate technical course to Physics I such as 15-110 or 03-121 so that their unit total is lower.

Spring

<table>
<thead>
<tr>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>09-106 Modern Chemistry II</td>
</tr>
<tr>
<td>Chemistry majors who place out of 09-106 can take 09-348 Inorganic Chemistry, 09-510 Chemistry and Sustainability as a chemistry elective or consult with the Director of Undergraduate Studies about the possibility of a suitable research placement.</td>
</tr>
<tr>
<td>21-122 Integration and Approximation</td>
</tr>
<tr>
<td>or 21-124 Calculus II for Biologists and Chemists</td>
</tr>
<tr>
<td>15-110 Principles of Computing or 33-121 Physics I for Science Students or 03-121 Modern Biology</td>
</tr>
</tbody>
</table>

48
## Distribution of Units for the B.A. in Chemistry

Minimum Total Chemistry Units: 124; See distribution below:

### Required Chemistry Courses

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>09-105</td>
<td>Introduction to Modern Chemistry I</td>
<td>10</td>
</tr>
</tbody>
</table>

### Sophomore Year

<table>
<thead>
<tr>
<th>Term</th>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>09-201</td>
<td>Undergraduate Seminar I</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>09-219</td>
<td>Modern Organic Chemistry</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>09-221</td>
<td>Laboratory I: Introduction to Chemical Analysis</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>33-122</td>
<td>Physics II for Biological Sciences &amp; Chemistry Students</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>xx-xxx</td>
<td>Arts, Humanities and Social Sciences Course 2</td>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Term</th>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>09-202</td>
<td>Undergraduate Seminar II: Safety and Environmental Issues for Chemists</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>09-204</td>
<td>Professional Communication Skills in Chemistry (it is recommended that this course be completed prior to taking the junior level labs, 09-321 or 09-323.)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>09-220</td>
<td>Modern Organic Chemistry II</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>09-222</td>
<td>Laboratory II: Organic Synthesis and Analysis</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>38-230</td>
<td>ENGAGE in Wellness: Looking Inward</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>xx-xxx</td>
<td>Arts, Humanities and Social Sciences Course 3</td>
<td>18</td>
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</table>

<table>
<thead>
<tr>
<th>Term</th>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>09-301</td>
<td>Undergraduate Seminar III</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>09-321</td>
<td>Laboratory III: Molecular Design and Synthesis</td>
<td>12</td>
</tr>
<tr>
<td>or 09-323</td>
<td>Biorganic Chemistry Laboratory</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>03-121</td>
<td>Modern Biology</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>or 15-110</td>
<td>Principles of Computing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>38-330</td>
<td>ENGAGE in Wellness: Looking Outward</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>xx-xxx</td>
<td>Free Elective</td>
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</tr>
</tbody>
</table>

### Junior Year

<table>
<thead>
<tr>
<th>Term</th>
<th>Course Code</th>
<th>Course Title</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>09-302</td>
<td>Undergraduate Seminar IV</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>09-348</td>
<td>Inorganic Chemistry</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>09-xxx</td>
<td>Chemistry Elective (See notes below regarding chemistry electives.)</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>38-301</td>
<td>PROPEL</td>
<td>6</td>
</tr>
<tr>
<td>xx-xxx</td>
<td>Cultural/Global Understanding Requirement</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>xx-xxx</td>
<td>Free Elective</td>
<td>9</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Term</th>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>09-401</td>
<td>Undergraduate Seminar V</td>
<td>1</td>
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<tr>
<td></td>
<td>09-xxx</td>
<td>Chemistry Elective</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>09-214</td>
<td>Physical Chemistry</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>38-430</td>
<td>ENGAGE in Wellness: Looking Forward</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>38-110</td>
<td>ENGAGE in Service</td>
<td>1</td>
</tr>
<tr>
<td>xx-xxx</td>
<td>Free Electives</td>
<td>25</td>
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<table>
<thead>
<tr>
<th>Term</th>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>09-402</td>
<td>Undergraduate Seminar VI</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>38-220</td>
<td>ENGAGE in the Arts</td>
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<tr>
<td>xx-xxx</td>
<td>Free Electives</td>
<td>40</td>
<td></td>
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</table>

### Senior Year

<table>
<thead>
<tr>
<th>Term</th>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>09-106</td>
<td>Modern Chemistry II</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>09-204</td>
<td>Professional Communication Skills in Chemistry</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>09-219</td>
<td>Modern Organic Chemistry</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>09-220</td>
<td>Modern Organic Chemistry II</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>09-214</td>
<td>Physical Chemistry</td>
<td>9</td>
</tr>
<tr>
<td>or 09-344</td>
<td>Physical Chemistry (Quantum): Microscopic Principles of Physical Chemistry</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>or 09-345</td>
<td>Physical Chemistry (Thermo): Macroscopic Principles of Physical Chemistry</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>09-348</td>
<td>Inorganic Chemistry</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>09-221</td>
<td>Laboratory I: Introduction to Chemical Analysis</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>09-222</td>
<td>Laboratory II: Organic Synthesis and Analysis</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>09-321</td>
<td>Laboratory III: Molecular Design and Synthesis</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>or 09-323</td>
<td>Biorganic Chemistry Laboratory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>09-xxx</td>
<td>Chemistry Seminars</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>09-xxx</td>
<td>Chemistry Electives</td>
<td>18</td>
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</tr>
<tr>
<td>09-322</td>
<td>Laboratory IV: Molecular Spectroscopy and Dynamics</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Distribution of Units for the B.A. in Chemistry

- **Fall**: 10 units
- **Spring**: 10 units
- **Total Sophomore Year**: 20 units

### Distribution of Units for the B.A. in Chemistry

- **Junior Year**: 41 units
- **Senior Year**: 44 units
- **Total Junior Year**: 41 units
- **Total Senior Year**: 44 units

### Notes on Electives

- **Chemistry Electives**: A minimum of 18 units of chemical electives is required.
- Chemical electives can be satisfied by 09-445 Undergraduate Research, or by most other chemistry courses 09-3xx or higher, undergraduate or graduate, for which the student has the necessary prerequisites.
- Requests for credit for work done previously elsewhere will be approved only under unusual or extenuating circumstances.
- Chemistry courses required for the B.A. degree that are numbered 09-2xx or higher must be taken at Carnegie Mellon University. Exceptions must be approved by and coordinated through the Director of Undergraduate Studies.

### Other Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biology (either Modern Biology or Biochemistry)</td>
<td>9</td>
</tr>
<tr>
<td>Computer Science</td>
<td>10</td>
</tr>
<tr>
<td>Mathematics</td>
<td>20</td>
</tr>
<tr>
<td>Physics</td>
<td>21</td>
</tr>
<tr>
<td>Interpretation and Argument</td>
<td>9</td>
</tr>
<tr>
<td>Arts, Humanities and Social Sciences courses</td>
<td>36</td>
</tr>
<tr>
<td>Cultural/Global Understanding</td>
<td>9</td>
</tr>
<tr>
<td>EUREKA! (First year seminar)</td>
<td>6</td>
</tr>
<tr>
<td>MCS Junior Seminar</td>
<td>6</td>
</tr>
<tr>
<td>ENGAGE in Wellness (3 courses)</td>
<td>3</td>
</tr>
<tr>
<td>ENGAGE in Service</td>
<td>1</td>
</tr>
<tr>
<td>ENGAGE in the Arts</td>
<td>2</td>
</tr>
<tr>
<td>Computing @ Carnegie Mellon</td>
<td>3</td>
</tr>
<tr>
<td>Free Electives</td>
<td>101</td>
</tr>
<tr>
<td>Minimum number of units for the degree</td>
<td>360</td>
</tr>
</tbody>
</table>

The above B.A. curriculum recommends a range of 40-50 units per semester. The total units actually taken may exceed the 360 unit minimum, but students are strongly encouraged to take the extra elective courses in whatever subjects they wish in order to enrich their backgrounds and enhance their educational experience.
or by 09-231/03-232 Biochemistry I. Biochemistry also fulfills the Life Sciences requirement for the MCS technical breadth requirement.

- 09-435 Independent Study Chemistry, may only be used to fulfill this requirement with permission of the Director of Undergraduate Studies. Certain interdisciplinary courses (e.g. 39-xxx) relating to chemistry can also be used with permission by the Director of Undergraduate Studies. The scheduling of these electives can vary and students should check with the department offering the course to see which courses are offered in any given year or semester and with the Director of Undergraduate Studies in the Department of Chemistry to ascertain whether the course is an acceptable chemistry elective.

**Free Electives**

Free electives are defined as including any course offered by Carnegie Mellon except those in science or engineering fields that are primarily intended for non-majors. A maximum of 9 units total of Physical Education and/or ROTC courses combined can be counted as free elective units. The Chemistry Department does not require technical electives.

**B.S. in Chemistry/Biological Chemistry Track**

This degree is ideal for students who wish to better prepare themselves for advanced studies in biological chemistry or biomedical fields and a job market that values knowledge and skills from both disciplines. A combination of advanced research-focused lecture course offerings and a new laboratory course will allow students to build the strong foundation typical of a successful chemistry major, while expanding out into applications of chemistry in the biological sciences.

**Curriculum - B.S. in Chemistry/Biological Chemistry Track**

This catalog and the sample schedules presented are intended to be used by students in the first year class entering in the fall of 2017. Upperclass students should refer to the appropriate previous version of the catalog published during their first year for the requirements that are specific to them.

The technical breadth requirement of the MCS core curriculum requires a minimum of four technical courses outside of the student’s primary major. Chemistry majors in the Biological Chemistry Track must at minimum take the following non-chemistry technical courses: 33-121 Physics I for Science Students, 33-122 Physics II for Biological Sciences & Chemistry Students, 03-121 Modern Biology, 15-110 Principles of Computing (or other approved programming course), 21-120 Differential and Integral Calculus and 21-122 Integration and Approximation or 21-124 Calculus II for Biologists and Chemists. Students should complete this technical core as early as possible and preferably by the end of their fifth semester.

The non-technical breadth requirements for MCS students includes 76-101 Interpretation and Argument, four courses with a minimum of 36 units from the arts, humanities or social sciences and a course of at least 9 units from an approved list in the category of Cultural/Global understanding, from the arts, humanities or social sciences and electives with permission of the Director of Undergraduate Studies. The maximum units allowed during the first semester is 54; therefore, students wishing to take a lab should take 03-121 Modern Biology so that their unit total is lower and they get a start on their required biology courses.

**Students interested in majoring in chemistry who have a strong chemistry background, should enroll in 09-107 rather than 09-105. Students who complete 09-107 with an A grade will be exempted from the requirement to take 09-106 Modern Chemistry II.**

02-201 Programming for Scientists is an acceptable alternative to 15-110 for chemistry majors as are any upper level courses in programming.

There are some elective laboratory courses offered for MCS students in the first year. These include 03-115 Phage Genomics Research and 09-122 Molecular Tools for Biological and Chemical Studies. The maximum units allowed during the first semester is 54; therefore, students wishing to take a lab should take 03-121 Modern Biology so that their unit total is lower and they get a start on their required biology courses.

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Free electives are defined as including any course offered by Carnegie Mellon except those in science or engineering fields that are primarily intended for non-majors. A maximum of 9 units total of Physical Education and/or ROTC courses combined can be counted as free elective units. The Chemistry Department does not require technical electives.

**Curriculum - B.S. in Chemistry/Biological Chemistry Track**

This catalog and the sample schedules presented are intended to be used by students in the first year class entering in the fall of 2017. Upperclass students should refer to the appropriate previous version of the catalog published during their first year for the requirements that are specific to them.

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The non-technical breadth requirements for MCS students includes 76-101 Interpretation and Argument, four courses with a minimum of 36 units from the arts, humanities or social sciences and a course of at least 9 units from an approved list in the category of Cultural/Global understanding, from the arts, humanities or social sciences and electives with permission of the Director of Undergraduate Studies. The maximum units allowed during the first semester is 54; therefore, students wishing to take a lab should take 03-121 Modern Biology so that their unit total is lower and they get a start on their required biology courses.
Students who transfer into the department and have taken 09-207 Techniques in Quantitative Analysis and/or 09-208 Techniques for Organic Synthesis and Analysis will be required to take a 3 unit transition course (09-215 Chemistry Tech I to Lab I Transition for 09-207 and/or 09-216 Chemistry Tech II to Lab II Transition for 09-208) to fulfill the major requirements for 09-221 and/or 09-222.

Chemistry courses required for the B.S. degrees that are numbered 09-2xx or higher must be taken at Carnegie Mellon University. Exceptions must be requested of and approved by the Director of Undergraduate Studies. In general such requests will be approved only under unusual or extenuating circumstances.

### Distribution of Units for the B.S. in Chemistry/Biological Chemistry Track

**Minimum Total Chemistry Units 190:** See distribution below

<table>
<thead>
<tr>
<th>Required Chemistry Courses* Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>09-105 Introduction to Modern Chemistry I</td>
</tr>
<tr>
<td>or 09-107 Honors Chemistry: Fundamentals, Concepts and Applications</td>
</tr>
<tr>
<td>09-106 Modern Chemistry II</td>
</tr>
<tr>
<td>09-204 Professional Communication Skills in Chemistry</td>
</tr>
<tr>
<td>09-219 Modern Organic Chemistry</td>
</tr>
<tr>
<td>09-220 Modern Organic Chemistry II</td>
</tr>
<tr>
<td>09-231 Biochemistry I</td>
</tr>
<tr>
<td>or 03-232 Biochemistry I</td>
</tr>
<tr>
<td>09-231 Mathematical Methods for Chemists</td>
</tr>
<tr>
<td>09-331 Modern Analytical Instrumentation</td>
</tr>
<tr>
<td>09-344 Physical Chemistry (Quantum): Microscopic Principles of Physical Chemistry</td>
</tr>
<tr>
<td>09-345 Physical Chemistry (Thermo): Macroscopic Principles of Physical Chemistry</td>
</tr>
<tr>
<td>09-518 Bioorganic Chemistry: Nucleic Acids and Carbohydrates</td>
</tr>
<tr>
<td>or 09-519 Bioorganic Chemistry: Peptides, Proteins and Combinatorial Chemistry</td>
</tr>
<tr>
<td>09-348 Inorganic Chemistry</td>
</tr>
<tr>
<td>09-221 Laboratory I: Introduction to Chemical Analysis</td>
</tr>
<tr>
<td>09-222 Laboratory II: Organic Synthesis and Analysis</td>
</tr>
<tr>
<td>09-323 Bioorganic Chemistry Laboratory</td>
</tr>
<tr>
<td>09-322 Laboratory IV: Molecular Spectroscopy and Dynamics</td>
</tr>
<tr>
<td>09-xxx Chemistry Seminars</td>
</tr>
<tr>
<td>09-xxx Biological Chemistry Electives</td>
</tr>
</tbody>
</table>

Students who transfer into the department and have taken 09-217 Organic Chemistry I and/or 09-218 Organic Chemistry II, will be required to complete units of 09-435 Independent Study Chemistry, 1 unit per course, under the supervision of the instructor(s) for 09-219 and/or 09-220 in order to master the course content missed in this course sequence.

### NOTES ON ELECTIVES

#### Biological Chemistry Electives

A list of currently approved electives is provided below. One semester of 09-445 for 9 units may be used for 1 biological chemistry elective with the approval of the Director of Undergraduate Studies. It must be part of a longer term experience ensuring depth of knowledge in the area.

- **09-518** Bioorganic Chemistry: Nucleic Acids and Carbohydrates
  - (One of these two courses is required for the degree. The other can be used as a Biological Chemistry elective.)
- **09-519** Bioorganic Chemistry: Peptides, Proteins and Combinatorial Chemistry
- **09-705** Chemosensors and Biosensors
- **09-521** Metals in Biology: Function and Reactivity
- **09-716** Bioactive Natural Products
- **09-737** Medicinal Chemistry and Drug Development
- **09-803** Chemistry of Gene Expression
- **03-220** Genetics
- **03-320** Cell Biology
- **03-344** Experimental Biochemistry
- **03-362** Cellular Neuroscience
- **03-366** Biochemistry of the Brain
- **03-439** Introduction to Biophysics
- **03-534** Biological Imaging and Fluorescence Spectroscopy
- **03-740** Advanced Biochemistry
- **03-871** Structural Biophysics
- **33-441** Introduction to BioPhysics

#### Free Electives

Free electives are defined as including any course offered by Carnegie Mellon except those in science or engineering fields that are primarily intended for non-majors. A maximum of 9 units total of Physical Education,
Options for the B.S. in Chemistry

The curriculum for the degree Bachelor of Science in Chemistry permits students to take a number of elective courses in chemistry and other fields, particularly in the junior and senior years. Students may wish to complete a group of elective courses from several specialty areas, called “options,” to complement their technical education. Each option will complement the Bachelor's degree in Chemistry and will provide students with expertise in a specific area not covered by the normal undergraduate curriculum. Options are noted on the student's transcript but not on the diploma.

For each of the following options, the student should refer to the previous description of the curriculum for the B.S. in chemistry. Required courses are unchanged, and the courses that should be taken as electives for each option are listed below. Chemistry courses within an option also count towards fulfillment of the chemistry elective requirement for the B.S. degree.

A student who completes the recommended courses for any of these options will be made on the student’s transcript. The Chemistry Department does not require technical electives.

The curriculum for the degree Bachelor of Science in Chemistry permits students to take a number of elective courses in chemistry and other fields, particularly in the junior and senior years. Students may wish to complete a group of elective courses from several specialty areas, called “options,” to complement their technical education. Each option will complement the Bachelor's degree in Chemistry and will provide students with expertise in a specific area not covered by the normal undergraduate curriculum. Options are noted on the student's transcript but not on the diploma.

For each of the following options, the student should refer to the previous description of the curriculum for the B.S. in chemistry. Required courses are unchanged, and the courses that should be taken as electives for each option are listed below. Chemistry courses within an option also count towards fulfillment of the chemistry elective requirement for the B.S. degree.

A student who completes the recommended courses for any of these options will be made on the student’s transcript. The Chemistry Department does not require technical electives.

### Options for the B.S. in Chemistry

#### BIOCHEMISTRY OPTION

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>03-231/232</td>
<td>Biochemistry I</td>
<td>9</td>
</tr>
<tr>
<td>03-330</td>
<td>Genetics</td>
<td>9</td>
</tr>
<tr>
<td>03-344</td>
<td>Experimental Biochemistry</td>
<td>12</td>
</tr>
<tr>
<td>xx-xxx</td>
<td>Elective in Biochemistry</td>
<td></td>
</tr>
</tbody>
</table>

Elective course may be chosen from the following list. (Other courses listed as electives for the Biological Chemistry Track may be with permission.)

- 03-439 Introduction to Biophysics
- 09-518 Bioorganic Chemistry: Nucleic Acids and Carbohydrates
- 09-519 Bioorganic Chemistry: Peptides, Proteins and Combinatorial Chemistry
- 03-740 Advanced Biochemistry

#### POLYMER SCIENCE OPTION

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>06-466</td>
<td>Experimental Polymer Science</td>
<td>9</td>
</tr>
<tr>
<td>09-502</td>
<td>Organic Chemistry of Polymers</td>
<td>9</td>
</tr>
<tr>
<td>09-509</td>
<td>Physical Chemistry of Macromolecules</td>
<td>9</td>
</tr>
<tr>
<td>09-xxx</td>
<td>Elective in Polymer Science</td>
<td>9</td>
</tr>
</tbody>
</table>

Elective course may be chosen from the following list

- 09-531 Polymer Science
- 09-445 Undergraduate Research

(9 units of 09-445 can count towards this option if part of a longer term immersion and approved by the Director of Undergraduate Studies)

#### ENVIROMENTAL CHEMISTRY OPTION

<table>
<thead>
<tr>
<th>Course Code</th>
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<th>Units</th>
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<tr>
<td>09-531</td>
<td>Polymer Science</td>
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</tr>
<tr>
<td>27-xxx</td>
<td>MSE course approved by Director of Undergraduate Studies</td>
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#### ENVIRONMENTAL CHEMISTRY OPTION

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>09-510</td>
<td>Chemistry and Sustainability</td>
<td>9</td>
</tr>
<tr>
<td>09-445</td>
<td>Undergraduate Research</td>
<td>Var.</td>
</tr>
</tbody>
</table>

(9 units of 09-445 can count towards this option if part of a longer term immersion and approved by the Director of Undergraduate Studies)

Two elective courses of at least 9 units each from the list below

- 09-225 Climate Change: Chemistry, Physics and Planetary Science
- 19-424 Energy and the Environment
- 19-440 Combustion and Air Pollution Control
- 12-651 Air Quality Engineering
- 12-657 Water Resource Systems Engineering
- 12-702 Fundamentals of Water Quality Engineering

#### MANAGEMENT OPTION

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<tr>
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<td>Global Business</td>
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<tr>
<td>73-102</td>
<td>Principles of Microeconomics</td>
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<tr>
<td>70-122</td>
<td>Introduction to Accounting</td>
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<td>70-364</td>
<td>Business Law</td>
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#### COMPUTATIONAL CHEMISTRY OPTION

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<tr>
<td>15-112</td>
<td>Fundamentals of Programming and Computer Science</td>
<td>12</td>
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<tr>
<td>15-122</td>
<td>Principles of Imperative Computation or 15-150 Principles of Functional Programming</td>
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<td>09-560</td>
<td>Computational Chemistry</td>
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<tr>
<td>21-127</td>
<td>Concepts of Mathematics</td>
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<td>xx-xxx</td>
<td>One Upper Level Computational Elective Course from the list below</td>
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<tr>
<td>15-210</td>
<td>Parallel and Sequential Data Structures and Algorithms</td>
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<td>15-213</td>
<td>Introduction to Computer Systems</td>
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<td>33-241</td>
<td>Introduction to Computational Physics</td>
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<td>03-250</td>
<td>Introduction to Computational Biology</td>
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<td>09-701</td>
<td>Quantum Chemistry I</td>
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<tr>
<td>09-702</td>
<td>Statistical Mechanics and Dynamics</td>
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### B.S. in Chemistry with Departmental Honors

Outstanding students with an interest in research are encouraged to consider the Honors program by the beginning of the junior year. The program combines a slightly modified B.S. curriculum with close faculty-student contact in an individual research project, concluding with the student's presentation and defense of a bachelor's honors thesis to a Thesis Committee.

The B.S. in Chemistry with Departmental Honors curriculum follows the general sequence of courses that is listed for the B.S. degree. Students are strongly urged to complete all seven of the Science Core Courses as early as possible. The honors program specifies that one of the two chemistry electives be a 12-unit course, numbered 09-7xx or higher, and that of the remaining electives required, at least two be undergraduate research (18 units) and one be 09-455 Honors Thesis (taken for 6 units). Students will be encouraged to do more than the minimum amount of research, so stipends from the research advisor or other sources are sometimes available for summer B.S. honors research.

At any time before the spring term of the senior year, candidates for the B.S. in chemistry may apply to be admitted for candidacy to the Honors B.S. program. Applications are available through the Director of Undergraduate Studies. To be accepted, students will be expected to have shown excellent performance in class work — normally at least a 3.2 average GPA. Upon acceptance into the program, a Thesis Committee must be identified, which will monitor the progress of the student. The committee shall consist of at least one member of the Undergraduate Program Committee to be appointed by the Director of Undergraduate Studies, the student's research advisor and a third faculty member agreed upon by the student and advisor. This third member can be from another department or institution and can be tenure track, teaching track or research track faculty.
It is the student's responsibility to contact the proposed third member of their committee and confirm their participation.

A written thesis suitable for an Honors B.S. degree is required and should be a clear exposition in proper scientific format of a research project done for at least 18 units of credit in 09-445 Undergraduate Research. The thesis should describe a substantive new contribution to a particular field of research. This could include, but is not limited to, the discovery of a new phenomenon, studies that enhance our understanding of a previously reported phenomenon, or the development of a new method or technique. The student's Thesis Committee will evaluate the thesis and will require that each student participate in a public oral presentation or defense of the thesis before it approves the Honors degree. The written thesis must be supplied to the members of the student's Thesis Committee no later than one week prior to the scheduled public defense. The defense is usually scheduled to take place during April or early May of the senior year and the Director of Undergraduate Studies will coordinate the selection of a suitable date. Students completing the B.S. with Departmental Honors in Chemistry will receive MCS College Honors as well.

The designations of MCS College Honors and Departmental Honors are noted on the transcript but not on the diploma. Only University Honors are noted on the diploma.

Honors B.S./M.S. Program in Chemistry

Outstanding students seeking an advanced degree are encouraged to apply for admission to the B.S./M.S. Honors program as early as they can but only after having made some progress on a research project that could eventually be suitable for production of a Master's level thesis. Please note that this degree is available only with the B.S. in chemistry and cannot be obtained by students pursuing a B.A. degree in chemistry. Most commonly, applications are submitted during the second half of the sophomore year or early in the junior year. Applications are available through the Director of Undergraduate Studies. Participants will have the opportunity to earn in four years not only the degree B.S. in Chemistry with Departmental Honors, but also the degree Master of Science in Chemistry. This program is highly research intensive and is not appropriate for all students. Requirements include completing five graduate level courses as electives. (See notes on Honors B.S./M.S. electives.)

The schedule of courses for the B.S./M.S. program generally moves as many courses as possible forward in the curriculum, though this is not a requirement. When possible, all Science Core Courses should be completed in the freshman year. This gives the student the following advantages: 1) greater perspective in selection of a research advisor; 2) greater maturity in performing independent research; and 3) the possibility of initiating the graduate course sequence in the junior year. Students can achieve this accelerated schedule through advanced placement or summer school though neither is a requirement.

A completed application, available from Karen Stump, kstump@andrew.cmu.edu, and written note of approval from the thesis advisor must be submitted to the Director of Undergraduate Studies who will then arrange for an application meeting with the student, research advisor and Honors Committee. At this meeting the student is expected to give an oral presentation with sufficient background information, a summary of work completed to date and a detailed plan for their thesis project.

Upon acceptance into the program, a Thesis Committee must be identified, which will monitor the progress of the student. The committee shall consist of at least one member of the Undergraduate Program Committee appointed by the Director of Undergraduate Studies, the student's research advisor and a third faculty member agreed upon by the student and advisor. This third member can be from another department or institution and can be tenure track, teaching track or research track faculty. It is the student's responsibility to contact the third member of their committee, confirm their participation and notify the Director of Undergraduate Studies.

The student is expected to keep the research advisor selected by May of the sophomore year for the duration of the thesis project. Summer thesis research for 10 weeks after the sophomore and junior years is strongly suggested to assist the student in completing research sufficient quantity and quality to complete their thesis. Students normally will be given stipends for their summer work either by their research advisor or by competing for a summer fellowship. A minimum of 3 semesters of undergraduate research is required (normally 10 units/semester), though this is rarely sufficient as the sole research experience, as is participation in group seminars during the junior and senior years. Students must present their research at least once at the Sigma Xi competition at Meeting of the Minds, the annual Carnegie Mellon undergraduate research symposium, typically at the end of the junior year. In addition students must meet with their Thesis Committee each fall to update the committee on their progress and in the fall of the senior year must prepare a written summary of their research progress to date (5 pages) and their plans for the academic year (1 page). This report must state clearly what stage the work is in; it must be clear what work is complete and ready for publication.

At the start of the spring semester of the senior year (or their final semester if different), the student must submit a draft of the introduction for their thesis and a detailed outline of their methods, results and discussion sections to the Director of Undergraduate Studies who also chairs the Honors Committee. The four page outline is distributed by the department and reviewed by the student's Thesis Committee.

Each student is required to submit a formal Masters Degree dissertation to the Chemistry Department in April of the senior year or at least one week prior to the date set for the thesis defense. The Thesis Committee will evaluate the written thesis and student is required to present their final oral defense of the project before the Thesis Committee. The defense is usually scheduled to take place during April or early May of the senior year and the Director of Undergraduate Studies will coordinate the selection of a suitable date. The public defense is followed by a private question and answer session with the Thesis Committee.

The dissertation, written in proper scientific format, should describe the research project in considerable detail and must withstand the scrutiny of the Thesis Committee with respect to completeness. It need not be as extensive nor contain the element of student originality characteristic of a Ph.D. thesis; however it must contain results and conclusions that are of a high enough quality to be accepted as a publication in a respected research journal. The student should refer to the ACS Style Guide for recommendations on appropriate presentation and formatting of written text tables, graphs, and equations. As for all M.S. candidates in the Department, the dissertation must be approved by the faculty member in charge of the work.

Research productivity is the most important criterion for success at the evaluation points, but QPA is a strong secondary criterion. While we expect that most students will maintain a QPA of 3.5, a minimum of 3.2 must be maintained to remain in the program and will be acceptable only with a strong record of research. Candidates must also maintain a QPA of at least 3.0 in the five graduate level courses required for the degree.

Students who complete this program will receive the designations of Departmental Honors and MCS College Honors. These are designated on the transcript, not on the diploma. Only University Honors are denoted on the diploma.

Students completing the requirements for this degree receive two diplomas, one for the B.S. degree and another for the M.S. degree. Since this is a combined degree program both degrees are awarded at the same time; the awarding of the two degrees cannot be separated in time.

Notes on Honors B.S./M.S. Electives

The B.S./M.S. Honors degree requires the completion of five graduate level courses. Graduate courses in chemistry are typically those numbered 09-7xx or 09-8xx. Courses numbered 09-6xx are generally remedial graduate level courses and not acceptable towards the degree requirements as the content overlaps extensively with required chemistry courses at the undergraduate level. Graduate classes in chemistry are normally 12-unit courses (or two six unit minis numbered 09-7xx or 09-8xx counting as one graduate level course). However, in order not to penalize interdisciplinary studies which may be essential to a good thesis, up to three of the five required graduate chemistry courses may be advanced undergraduate (9-unit) courses in MCS and/or approved CIT departments. All advanced undergraduate level courses used to satisfy this requirement must be approved by the Director of Undergraduate Studies.

Curriculum - B.S. with Departmental Honors / M.S. in Chemistry

This catalog and the sample schedules presented are intended to be used by students in the first year class entering in the fall of 2017. Upperclass students should refer to the appropriate previous version of the catalog published during their first year for the requirements that are specific to them.

The technical breadth requirement of the MCS core curriculum requires a minimum of four technical courses outside of the student's primary major. Chemistry majors must at minimum take the following non-chemistry technical courses: 33-121 Physics I for Science Students, 33-122 Physics II for Physical Sciences and Chemistry Students, either 09-121 or 09-121A Kursatri, 09-231 Biochemistry I, or 09-232 Biochemistry II, 15-110 Principles of Computing (or other approved programming course), 21-120 Differential and Integral Calculus and 21-122 Integration and Approximation or 21-124 Calculus II for Biological Sciences and Chemistry. Students should complete this technical core as early as possible and preferably by the end of their fifth semester.
The non-technical breadth requirements for MCS students includes 76-101 Interpretation and Argument, four courses with a minimum of 36 units from the arts, humanities or social sciences and a course of at least 9 units from an approved list in the category of Cultural/Global understanding, three ENGAGE in Wellness courses, 38-230 ENGAGE in Wellness: Looking Inward, 38-330 ENGAGE in Wellness: Looking Outward and 38-430 ENGAGE in Wellness: Looking Forward, 38-110 ENGAGE in Service, 38-220 ENGAGE in the Arts, 38-101 EUREKA!: Discovery and Its Impact, the MCS first-year seminar, and 38-301 PROPEL for a total of 72 units. For more information on allowed courses in the arts, humanities and social sciences and electives in the Cultural/Global Understanding category refer to the MCS section of this catalog.

SHS students have their own core education requirements. Please refer to the Intercollege Programs section of this catalog for the SHS requirements. Requests for exceptions within the SHS core must be made to the Director of the SHS program.

### First Year

<table>
<thead>
<tr>
<th>Semester</th>
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<th>Courses</th>
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<td>09-105 Introduction to Modern Chemistry I 10</td>
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<tr>
<td></td>
<td></td>
<td>09-107 Honors Chemistry: Fundamentals, Concepts and Applications 10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21-120 Differential and Integral Calculus 10</td>
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<td></td>
<td></td>
<td>33-121 Physics I for Science Students 12</td>
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<td></td>
<td></td>
<td>38-101 EUREKA!: Discovery and Its Impact 6</td>
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<tr>
<td></td>
<td></td>
<td>76-101 Interpretation and Argument 9</td>
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<td></td>
<td>99-101 Computing @ Carnegie Mellon 3</td>
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<tr>
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</table>

Students interested in majoring in chemistry who have a strong chemistry background, should enroll in 09-107 rather than 09-105. Students who complete 09-107 with an A grade will be exempted from the requirement to take 09-106 Modern Chemistry II.

02-201 Programming for Scientists is an acceptable alternative to 15-110 for chemistry majors as are any upper level courses in programming. These include 03-115 Phage Genomics Research and 09-122 Molecular Tools for Biological and Chemical Studies.

### Spring

<table>
<thead>
<tr>
<th>Semester</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>09-106 Modern Chemistry II 10</td>
</tr>
</tbody>
</table>

**Chemistry majors who place out of 09-106 can take 09-348 Inorganic Chemistry, 09-510 Chemistry and Sustainability as a chemistry elective or inquire with the Director of Undergraduate Studies about a suitable research placement.**

<table>
<thead>
<tr>
<th>Semester</th>
<th>Units</th>
<th>Courses</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>21-122 Integration and Approximation 10</td>
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<tr>
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<td>15-110 Principles of Computing 10</td>
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<td></td>
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<td>33-121 Physics I for Science Students 10</td>
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<td>03-121 Modern Biology 10</td>
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<tr>
<td></td>
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<td>xx-xxx Arts, Humanities and Social Sciences Course 1 9</td>
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### Sophomore Year

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<td></td>
<td>09-219 Modern Organic Chemistry 10</td>
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<td></td>
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<td>09-221 Laboratory I: Introduction to Chemical Analysis 12</td>
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<td></td>
<td></td>
<td>09-201 Undergraduate Seminar I 1</td>
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<td></td>
<td></td>
<td>33-122 Physics II for Biological Sciences &amp; Chemistry 9</td>
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<td>09-445 Undergraduate Research 9</td>
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<td></td>
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<td>xx-xxx Arts, Humanities and Social Sciences Course 2 9</td>
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<tr>
<td><strong>Spring</strong></td>
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<td>09-202 Undergraduate Seminar II: Safety and Environmental Issues for Chemists 1</td>
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### Junior Year

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<td>09-301 Undergraduate Seminar III 1</td>
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<tr>
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<td>09-231 Mathematical Methods for Chemists 9</td>
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<td>09-321 Laboratory III: Molecular Design and Synthesis 12</td>
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<td>09-344 Physical Chemistry (Quantum): Microscopic Principles of Physical Chemistry 9</td>
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<td>09-445 Undergraduate Research 9</td>
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<td>38-330 ENGAGE in Wellness: Looking Outward 1</td>
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<td>xx-xxx Arts, Humanities and Social Sciences Course 4 9</td>
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<td><strong>Spring</strong></td>
<td></td>
<td>09-302 Undergraduate Seminar IV 1</td>
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<td>09-322 Laboratory IV: Molecular Spectroscopy and Dynamics 12</td>
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<td>09-445 Undergraduate Research 9</td>
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<td>09-xxx Graduate Chemistry Course 1 of 5 (see notes on Honors B.S./M.S. electives) 9</td>
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<td>09-345 Physical Chemistry (Thermo): Macroscopic Principles of Physical Chemistry 9</td>
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<td>09-331 Modern Analytical Instrumentation 9</td>
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<tr>
<td><strong>Summer</strong></td>
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### Senior Year

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<td>09-445 Undergraduate Research 9</td>
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<td>09-xxx Graduate Chemistry Course 2 of 5 12</td>
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<td>09-xxx Graduate Chemistry Course 3 of 5 12</td>
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<td>xx-xxx Cultural/Global Understanding 9</td>
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<td>38-430 ENGAGE in Wellness: Looking Forward 1</td>
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<td>09-402 Undergraduate Seminar VI 3</td>
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<td>38-220 ENGAGE in the Arts 2</td>
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### Distribution of Units for the B.S. with Departmental Honors/M.S. Degrees

**Minimum Total Chemistry Units (241, See distribution below)**

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<tr>
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**Required Chemistry Courses**

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**Honors Chemistry: Fundamentals, Concepts and Applications**

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**Modern Chemistry II**

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<td>10</td>
</tr>
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that the minor designation can be approved prior to graduation. The
intentions in writing using the MCS form for declaration of a minor so
pursuing the minor must inform the Chemistry Department of their
completion of six courses as distributed below is required. Students
a B.S. or B.A. degree from another (primary) department, the successful
intended for non-majors. A maximum of 9 units total of Physical Education,
Mellon except those in science or engineering fields that are primarily
Free electives are defined as including any course offered by Carnegie
Free Electives

Students who transferred into the department and have taken 09-217 Organic
Techniques in Quantitative Analysis and/or 09-208 Techniques for Organic
which majoring in chemical engineering. Students who take 09-347 may not use a
combination of physical chemistry courses (09-344, 09-345, 09-347 and
09-347 Advanced Physical Chemistry 12
09-348 Inorganic Chemistry 10

Courses in this group that are not used to satisfy Part A core courses may be
satisfy that department’s required chemistry or advanced chem/biochem
elective. Also, chemical engineering majors cannot use 09-344, 09-345 or
satisfy that department’s required chemistry or advanced chem/biochem
elective courses for the minor in chemistry. Chemical engineering majors
example, students majoring in Biological Sciences cannot double count
towards an additional major or minor other than as a free elective. For

Department of Chemistry

A. Four Required Core Courses

09-106 Modern Chemistry I 10
09-221 Laboratory I: Introduction to Chemical Analysis 12 or 09-207 Techniques in Quantitative Analysis 9-12
09-217 Organic Chemistry I 9-10
or 09-219 Modern Organic Chemistry
Choice of one of the following courses:
09-214 Physical Chemistry 9
09-344 Physical Chemistry (Quantum): Microscopic Principles of Physical Chemistry 9
09-345 Physical Chemistry (Thermo): Macroscopic Principles of Physical Chemistry 9
09-347 Advanced Physical Chemistry 12
09-348 Inorganic Chemistry 10

Courses in this group that are not used to satisfy Part A core courses may be
satisfy elective course requirements in part B below, if they are not
required by the student’s primary department. However the only combination of physical chemistry courses (09-344, 09-345, 09-347 and
09-214) that is allowed is 09-344 and 09-345.

Enrollment in 09-347 Advanced Physical Chemistry is only open to students
majoring in chemical engineering. Students who take 09-347 may not use a
second physical chemistry course as an elective.

B. Two Elective Courses from the following list.

09-344 Physical Chemistry (Quantum): Microscopic Principles of Physical Chemistry 9
09-214 Physical Chemistry 9
09-345 Physical Chemistry (Thermo): Macroscopic Principles of Physical Chemistry 9
09-348 Inorganic Chemistry 10
09-222 Laboratory II: Organic Synthesis and Analysis 9-12 or 09-208 Techniques for Organic Synthesis and Analysis
09-218 Organic Chemistry II 9-10
09-220 Modern Organic Chemistry II
03-231/232 Biochemistry I 9
09-xxx Approved Upper Level Chemistry Course (must be 09-3xx or higher but see exclusions noted below)

Courses in this section (part B above) can not be counted toward the minor
if they are required in any way by the student’s primary department or
towards an additional major or minor other than as a free elective. For
example, students majoring in Biological Sciences can not double count
03-231 (03-232), 09-208 (09-222), or 09-218 (09-220) toward the elective courses for the minor in chemistry. Chemical engineering majors
can not count 03-231 (03-232) or a chemistry course that is used to
satisfy that department’s required chemistry or advanced chem/biochem
elective. Also, chemical engineering majors can not use 09-344, 09-345 or
09-214 due to the similarity of these courses to 09-347 Advanced Physical
Chemistry, which is required by the chemical engineering department.

09-231 Mathematical Methods for Chemists, does not count towards
the minor in chemistry. The undergraduate research course 09-445
Undergraduate Research and 09-435 Independent Study Chemistry cannot
be used for the minor.

Transfer credit will be accepted only for the prerequisite 09-105, 09-106
and 09-217. All other classes towards the chemistry minor must be
completed at Carnegie Mellon University.

Minor in Chemistry

In order for a student to receive a minor in Chemistry in conjunction with
a B.S. or B.A. degree from another (primary) department, the successful
completion of six courses as distributed below is required. Students
pursuing the minor must inform the Chemistry Department of their
intentions in writing using the MCS form for declaration of a minor so
that the minor designation can be approved prior to graduation. The
form may be obtained from the MCS undergraduate web page, http://
www.cmu.edu/mcs/undergrad/advising/forms/index.html. It should be
completed and submitted to the department office, DH 1317, no
later than the end of the course add period of the final semester
prior to graduation. If you decide at a later date not to complete the
minor, it would be helpful to notify the Director of Undergraduate Studies,
ks01@andrew.cmu.edu, so that it can be removed from your record. Minors
are listed on the transcript but not on the diploma.

Note: An introductory chemistry class equivalent to either 09-105
Introduction to Modern Chemistry I or 09-107 Honors Chemistry:
Fundamentals, Concepts and Applications is a presupposed prerequisite
beginning the minor in chemistry.
Transfer Credit for Chemistry Courses

1. Requests for transfer credit for chemistry classes taken at other institutions should be made to Karen Stump, the Director of Undergraduate Studies in the Department of Chemistry. Students making such requests should follow the policies and procedures in place within their home colleges in assembling materials for such requests. Consult with your advisor on the appropriate steps.

2. At minimum requests must be accompanied by a complete syllabus including the textbook that will be used, a detailed list of topic areas and an indication of whether or not the course is part of the curriculum for science majors at the other institution.

3. No transfer credit will be awarded for the laboratory classes required for the chemistry or biology major at Carnegie Mellon University, 09-207, 09-221, 09-208, 09-222, 09-321, 09-323 and 09-322. Requests for transfer credit for 09-101, Introduction to Experimental Chemistry, will be accepted with the appropriate documentation.

4. In assessing the suitability of courses for transfer credit, the following factors are considered:
   - The rigor of the course must be comparable to that offered at Carnegie Mellon. This is usually assessed via the textbook used and the amount of time spent on topic areas.
   - The topic areas should match to a degree of at least 80% those covered in the comparable course at Carnegie Mellon University.

5. 09-105 Introduction to Modern Chemistry I focuses primarily on structure and bonding. Detailed topics include the following:
   - History and Conceptual Basis of Modern Chemistry
   - Radiation, Quantum Mechanics, and Atomic Structure
   - Periodic Table and Trends in Elemental Properties (including discussion of exceptions to trends)
   - Bonding (bond polarity)
   - Lewis Structures (octet rule and exceptions; formal charge)
   - Resonance Structures
   - Molecular shapes
   - Molecular Polarity
   - Naming compounds
   - Intermolecular (intermolecular) forces and comparing physical properties from them
   - Valence Bond (Localized Electron) and Molecular Orbital Theory
   - Determining number of moles and chemical formulas
   - Writing and balancing chemical equations (in particular completing combustion and double displacement reactions – including acid-base and precipitation reactions)
   - Stoichiometry – limiting reactant and percentage yield
   - Gases (mainly ideal) and stoichiometric applications involving them
   - Phase transitions
   - Solutions (determining concentrations, dilution problems, stoichiometric applications, application of solubility rules to determine precipitate forms)
   - Acid-base reactions, titrations and other stoichiometric applications of acid-base reactions
   - Oxidations Numbers and Redox Reactions/Titrations (including balancing redox reactions) and other stoichiometric applications of redox reactions
   - Colligative Properties: Mixtures and Distillation
   - Transition Metal Complexes and Crystal Field Theory (including crystal field stabilization energy and optical properties)

6. 09-106 Modern Chemistry II focuses primarily on thermodynamics, kinetics and equilibrium. Detailed topic areas include the following:
   - Thermochemistry and Thermodynamics (First, Second, and Third Laws, with gas expansion/compression applications, including reversible, adiabatic processes)
   - Internal energy, enthalpy, entropy, Gibbs Free energy, and determination of spontaneity
   - Kinetics: Determination of rate, order, rate laws (including application of pseudo-rate laws, application of integrated rate laws to determine order, relationship between time and amount in a reaction, and half-life
   - Reaction mechanisms – applying fast equilibrium and steady-state approximations to determine rate law consistent with mechanism
   - Chemical Equilibria: determination of Q and K expressions, determination of direction in which reaction proceeds to achieve equilibrium (using Q and Le Chatelier’s principles, quantitative calculations to determine K or amounts at various stages, dependence of K on temperature, relationship between Gibbs Free energy, Q, and K)
   - Acid-Base Equilibria: writing dissociation equilibrium reactions and acid-base “neutralization” reactions, autoionization of water (determination of pH and pOH, use of Kw), writing Ka and Kb expressions from dissociation equilibria, quantitative equilibrium calculations for weak acids and bases, titrations between strong species, strong-weak species, and weak-weak species, buffers (calculations of pH and amounts, including how to make a buffer), polyprotic species (quantitative applications and titrations), solubility and precipitation equilibrium, determination of Ksp expressions and quantitative applications of those expressions, complex ion formation equilibria, emphasis is placed on equilibrium problems that involve multiple types of simultaneous equilibria
   - Electrochemistry: Electrochemical cell notation and writing half-reactions from it, Faraday constant to connect number of moles of electrons / reaction amounts with current, connection of Gibbs Free Energy to cell voltage (potential) at equilibrium and non-equilibrium conditions, determination of K’s (acid-base, solubility constants) or amounts using Nernst equation in concentration cells (K for cell reaction)

Faculty

Catalina Achim, Professor of Chemistry – Ph.D., Carnegie Mellon; Carnegie Mellon, 2001–.

William Alba, Associate Teaching Professor of Chemistry – Ph.D., University of California at Berkeley; Carnegie Mellon, 2005–.

Bruce A. Armitage, Professor of Chemistry – Ph.D., University of California at Berkeley; Carnegie Mellon, 1997–.

Ravichandra Bachi, Assistant Teaching Professor at Carnegie Mellon University-Qatar – Ph.D., Hunter College and The Graduate Center, CUNY; Carnegie Mellon, 2015–.

Stefan Bernhard, Professor of Chemistry – Ph.D., University of Fribourg (Switzerland); Carnegie Mellon, 2009–.

Mark E. Bier, Research Professor and Director, Center for Molecular Analysis – Ph.D., Purdue University; Carnegie Mellon, 1996–.

Emile Bominara, Associate Research Professor – Ph.D., University of Amsterdam (The Netherlands); Carnegie Mellon, 1994–.

Marcel P. Bruciez, Professor of Chemistry – Ph.D., University of California; Berkeley; Carnegie Mellon, 2006–.

Terrence J. Collins, Teresa Heinz Professor in Green Chemistry, Director, Institute for Green Science – Ph.D., University Auckland, (New Zealand); Carnegie Mellon, 1998–.

Subha R. Das, Associate Professor of Chemistry – Ph.D., Auburn University; Carnegie Mellon, 2006–.

Neil M. Donahue, Thomas Lord Professor of Chemistry, Professor of Chemical Engineering and Public Policy; Director, Steenbrenner Institute for Environmental Education and Research – Ph.D., Massachusetts Institute of Technology; Carnegie Mellon, 2000–.

Rebecca Freeland, Associate Head, Department of Chemistry – Ph.D., Carnegie Mellon; Carnegie Mellon, 1993–.

Robert Gil, Research Professor and Director, NMR Facility – Ph.D., Córdoba National University (Argentina); Carnegie Mellon, 2002–.

Susan T. Graul, Associate Teaching Professor – Ph.D., Purdue University; Carnegie Mellon, 1992–.

Yisong (Alex) Guo, Assistant Professor of Chemistry – Ph.D., University of California at Davis; Carnegie Mellon, 2014–.

Michael P. Hendrich, Professor of Chemistry – Ph.D., University of Illinois; Carnegie Mellon, 1994–.

Rongchao Jin, Professor of Chemistry – Ph.D., University of Pittsburgh; Carnegie Mellon, 2003–.
DANITH LY, Professor of Chemistry – Ph.D., Georgia Tech; Carnegie Mellon, 2001–.

KRZYSZTOF MATYASIWSKI, J.C. Warner University Professor of Natural Sciences and Director, Center for Macromolecular Engineering – Ph.D., Polish Academy of Sciences (Poland); Carnegie Mellon, 1986–.

KEVIN NOONAN, Associate Professor of Chemistry – Ph.D., University of British Columbia (Canada); Carnegie Mellon, 2011–.

HUNAID NULWALA, Assistant Research Professor – Ph.D., University of California at Santa Barbara; Carnegie Mellon, 2013–.

GARY D. PATTERSON, Professor of Chemistry and Department Head – Ph.D., University of Chicago; Carnegie Mellon, 1992–.

LINDA A. PETEANU, Professor of Chemistry and Department Head – Ph.D., University of California at Berkeley; Carnegie Mellon, 2015–.

GIZELLE SHERWOOD, Assistant Teaching Professor – Ph.D., Carnegie Mellon University; Carnegie Mellon, 2009–.

GLORIA SILVA, Assistant Teaching Professor – Ph.D., Universidad Nacional de Córdoba (Argentina); Carnegie Mellon, 2002–.

KAREN H. STUMP, Teaching Professor and Director of Undergraduate Studies and Laboratories – M.S., Carnegie Mellon University; Carnegie Mellon, 1983–.

RYAN SULLIVAN, Assistant Professor of Chemistry and Mechanical Engineering – Ph.D., University of California, San Diego; Carnegie Mellon, 2012–.

STEFANIE SYDLIK, Assistant Professor of Chemistry – Ph.D., Massachusetts Institute of Technology; Carnegie Mellon, 2015–.

LEONARD VUOCOLO, Assistant Teaching Professor – Ph.D., Carnegie Mellon University; Carnegie Mellon, 2006–.

NEWELL WASHBURN, Associate Professor of Chemistry and Biomedical Engineering – Ph.D., University of California, Berkeley; Carnegie Mellon, 2004–.

DAVID YARON, Professor of Chemistry – Ph.D., Harvard University; Carnegie Mellon, 1992–.

Emeriti

GUY C. BERRY, University Professor Emeritus of Chemistry and Polymer Science – Ph.D., University of Michigan; Carnegie Mellon, 1960–.

ALBERT A. CARETTO JR., Professor Emeritus of Chemistry – Ph.D., University of Rochester; Carnegie Mellon, 1959–.

JOSEF DADOK, Professor Emeritus of Chemical Instrumentation – Ph.D., Czechoslovak Academy of Sciences; Carnegie Mellon, 1967–.

PAUL J. KAROL, Professor Emeritus of Chemistry – Ph.D., Columbia University; Carnegie Mellon, 1969–.

ROBERT L. KAY, Professor Emeritus of Chemistry – Ph.D., University of Toronto; Carnegie Mellon, 1963–.

MIGUEL LLINAS, Professor Emeritus of Chemistry – Ph.D., University of California at Berkeley; Carnegie Mellon, 1976–.

ECKARD MÜNCK, Professor Emeritus of Chemistry – Ph.D., Technical University of Darmstadt (Germany); Carnegie Mellon, 1990–.

STUART W. STALEY, Professor Emeritus of Chemistry – Ph.D., Yale University; Carnegie Mellon, 1986–.

CHARLES H. VAN DYKE, Associate Professor Emeritus of Chemistry – Ph.D., University of Pennsylvania; Carnegie Mellon, 1963–.

Adjunct Faculty

JOHN PETERSON MYERS, CEO and Chief Scientist of Environmental Health Sciences – Ph.D., University of California at Berkeley; Carnegie Mellon, 2010–.

Courtey

MICHAEL BOCKSTALLER, Professor of Materials Science Engineering and Faculty of Chemistry – Ph.D., Johannes Gutenberg University (Germany); Carnegie Mellon, 2005–.

ALEX EVILEVITCH, Associate Professor of Physics and Faculty of Chemistry – Ph.D., Lund University; Carnegie Mellon, 2009–.

ANDREW GELLMAN, Thomas Lord Professor of Chemical Engineering, Faculty of Materials Science Engineering and Chemistry; Co-Director W.E. Scott Institute for Energy Innovation – Ph.D., University of California, Berkeley; Carnegie Mellon, 1992–.

NOA MAROM, Assistant Professor of Materials Science Engineering and Faculty of Chemistry – Ph.D., Weizmann Institute of Science (Israel); Carnegie Mellon, 2006–.

GORDON RULE, Professor of Biological Sciences and Faculty of Chemistry – Ph.D., Carnegie Mellon University; Carnegie Mellon, 1995–.

ALAN J. RUSSELL, Highmark Distinguished Career Professor, Institute for Complex Engineered Systems and Biomedical Engineering – Ph.D., Imperial College of Science and Technology (London); Carnegie Mellon, 2012–.

JAMES SCHNEIDER, Professor of Chemical Engineering and Faculty of Biomedical Engineering and Chemistry – Ph.D., University of Minnesota; Carnegie Mellon, 1999–.

ALAN S. WAGGONER, Maxwell H. & Gloria C. Conner Professor of Life Sciences, Faculty of Biomedical Engineering and Chemistry – Ph.D., University of Oregon; Carnegie Mellon, 1982–.

LYNN WALKER, Professor of Chemical Engineering and Faculty of Chemistry and Materials Science Engineering – Ph.D., University of Delaware; Carnegie Mellon, 1997–.

JOHN L. WOOLFORD JR., Professor of Biological Sciences; Co-Director of CNAST and Faculty of Chemistry – Ph.D., Duke University; Carnegie Mellon, 1979–.