

# Department of Chemistry

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*Carnegie Mellon provides a family-like but very vibrant and interdisciplinary environment for science students. One of our major strengths is that most of our undergraduate students in chemistry and related fields get involved in research in faculty labs early on and get hands-on experience in cutting-edge research, some even as freshmen. Our curriculum is both fluid and innovative to give students broad background and in-depth knowledge in chemistry and interdisciplinary areas.* —Dr. Hyung J. Kim

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, 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 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, plastics, metals, and pharmaceutical industries. Chemistry plays an increasingly important role in the rapidly expanding biomedical and biotechnology industries. 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 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 a 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 go on to study for an M.B.A.

The Department offers two degrees: the B.S. and the B.A. One third of the courses for the B.A. degree are free electives that may be taken in any of the departments of the University and therefore offer a high degree of flexibility. For the B.S. degree, electives normally are technical courses in chemistry or related fields of sciences, such as biology, physics, mathematics, 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, allowing students the flexibility to combine electives in the senior year into a focused program of specialization. One of these programs is the B.S. in chemistry with the computational chemistry track. The track is an intense concentration in coursework related to scientific computing. Students interested in graduate studies in chemistry may enroll in graduate lecture 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. Carnegie Mellon has one of the strongest polymer science programs in the country and the undergraduate polymer science option offers training that is particularly valuable for an industrial career. The Computational Chemistry track provides students with expertise in scientific computing that is highly sought after by employers in the pharmaceutical industry.

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, a research project, and the writing of a bachelor's 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 track is especially attractive to students who have earned advanced placement credit in one or more science and/or mathematics courses at Carnegie Mellon. 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.

Additional majors (double majors) are available with nearly all other departments 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). Students interested in biochemistry, for example, could pursue a B.S. in Chemistry with an Additional Major in Biological Sciences. 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 H&SS (Humanities and Social Sciences) college. 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 current requirements and further guidance. 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. 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 or Biotechnology Management.

Study abroad exchange 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. A language program of 3 months duration during the summer is available to students at no extra tuition cost. Study abroad is encouraged by the chemistry department and also can be arranged on an individual basis at universities in Europe, Asia, New Zealand, and Australia during both the academic year and the summer. Students interested in study abroad should consult with their academic advisor and the University's Study Abroad Advisor.

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 new state-of-the-art facility. Participation in undergraduate research is encouraged and qualified students may begin projects as early as their second year. Approximately 80 to 90% of the graduating chemistry majors 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) from the University to help support their research projects. Undergraduate and research laboratories are equipped with the latest scientific instrumentation. The use of computers is emphasized throughout the curriculum.

## Curriculum – B.S. in Chemistry

The MCS curriculum requires seven Science Core Courses to be completed by the end of the junior year. These are: 21–120 (Differential and Integral Calculus), 21–122 (Integration, Differential Equations and Approximation), 33–111 (Physics I for Science Students), 33–112 (Physics II for Science Students), 09–105 (Introduction to Modern Chemistry), 03–121 (Modern Biology), and 15–100\* (Introductory/Intermediate Programming). In the sample curriculum given below for chemistry majors, six of these are in the first year. Students should take the last Science Core Course as early as possible and by the end of their sixth semester. Course 09–106 (Modern Chemistry II) is defined as a Technical MCS Elective.

## First Year

	Fall (Four Course Schedule)	Units
09-105	Introduction to Modern Chemistry	10
21-120	Differential and Integral Calculus	10
33-111	Physics I for Science Students	12
76-101	Interpretation and Argument	9
99-101	Computing @ Carnegie Mellon	3

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Students interested in majoring in chemistry should consider enrolling in the 3-unit lab course 09-101, Introduction to Experimental Chemistry, in the fall or spring semester of the freshman year. Although not required, the laboratory course is recommended for chemistry majors.

	Spring	Units
09-106	Modern Chemistry II	10
21-122	Integration, Differential Equations and Approximation	10
33-112	Physics II for Science Students	12
15-100	Introductory/Intermediate Programming (or core elective)	10
xx-xxx	H&SS Distribution Course 1	9

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## Sophomore Year

	Fall	Units
09-201	Undergraduate Seminar I	1
09-219	Modern Organic Chemistry I	10
09-221	Laboratory I: Introduction to Chemical Analysis	12
09-231	Mathematical Methods for Chemists	9
03-121	Modern Biology (or core elective)	9
xx-xxx	H&SS Distribution Course 2	9

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	Spring	Units
09-202	Undergraduate Seminar II	1
09-204	Professional Communication Skills in Chemistry	3
09-220	Modern Organic Chemistry II	10
09-222	Laboratory II: Organic Synthesis and Analysis	12
09-348	Inorganic Chemistry	10
xx-xxx	H&SS Distribution Course 3	9

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## Junior Year

	Fall	Units
09-301	Undergraduate Seminar III	1
09-321	Laboratory III: Molecular Design and Synthesis	12
09-344	Physical Chemistry (Quantum)	9
09-331	Modern Analytical Instrumentation	9
xx-xxx	H&SS/CFA Elective 1 (of 4)*	9

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	Spring	Units
09-302	Undergraduate Seminar IV	1
09-322	Laboratory IV: Molecular Spectroscopy and Dynamics	12
09-345	Physical Chemistry (Thermo)	9
09-xxx	Chemical Elective (see Notes on Electives)	9
xx-xxx	H&SS/CFA Elective 2 (of 4)*	9

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## Senior Year

	Fall	Units
09-401	Undergraduate Seminar V	1
09-xxx	Chemical Elective (see notes on electives)	9
xx-xxx	Free Electives	27
xx-xxx	H&SS/CFA Elective 3 (of 4)*	9

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	Spring	Units
09-402	Undergraduate Seminar VI	3
xx-xxx	Electives	36
xx-xxx	H&SS/CFA Elective 4 (of 4)*	9

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\* Certain non-technical courses from Business Administration, Heinz School, and EPP also may be used. A listing of approved and non-approved courses for the H&SS/CFA electives is available at the following web site, [www.cmu.edu/mcs/education/edu\\_HSSFA.html](http://www.cmu.edu/mcs/education/edu_HSSFA.html), or see the Mellon College of Science section in this catalog for the Humanities and Social Sciences and Fine Arts Requirements. Accounting, finance, management, marketing, production, and statistics courses may NOT be used. Also, 70-100 (Introduction to Business) and 85-219 (Biological Foundations of Behavior) may NOT be used as electives in the H&SS/CFA category. If in doubt, check with your advisor.

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

Minimum Total Chemistry Units (163; See distribution below)

Required Chemistry Courses*	Units	
09-105	Introduction to Modern Chemistry**	10
09-106	Modern Chemistry II	10
09-204	Professional Communication Skills in Chemistry	3
09-219	Modern Organic Chemistry I ****	10
09-220	Modern Organic Chemistry II ****	10
09-231	Mathematical Methods for Chemists***	9
09-331	Modern Analytical Instrumentation	9
09-344	Physical Chemistry (Quantum)	9
09-345	Physical Chemistry (Thermo)	9
09-348	Inorganic Chemistry	10
09-221	Lab I: Introduction to Chemical Analysis	12
09-222	Lab II: Organic Synthesis and Analysis	12
09-321	Lab III: Molecular Design and Synthesis	12
09-322	Lab IV: Molecular Spectroscopy and Dynamics	12
09-xxx	Chemistry Seminars	8
09-xxx	Chemistry Electives	18

\* These, plus 33-111 Physics I for Science Students and 33-112 Physics for Science Students II, are the required courses for students earning an additional major in chemistry.

\*\* 09-107, Honors Chemistry, may be taken instead of 09-105.

\*\*\* 21-259, Calculus in Three Dimensions, and an additional Mathematics/Statistics Elective (see Notes on Electives below) can be taken to fulfill the requirement for 09-231.

\*\*\*\* 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 in Chemistry, 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.

Other Requirements	Units
Biology	9
Computer Science	10
Mathematics	20
Physics	24
Humanities and Social Sciences or Fine Arts courses	72
Free Electives	61
Computing @ Carnegie Mellon	3

Minimum number of units required for the degree: 360

The above B.S. curriculum recommends a range of 40-51 units/semester to meet the minimum degree requirement. Students are strongly encouraged to take extra elective courses (except in the first semester of the freshman year) in whatever subjects they wish in order to enrich their backgrounds and enhance their educational experience.

## Notes on Electives

### Mathematics/Statistics Elective

The B.S. degree in Chemistry requires 09-231 (Mathematical Methods for Chemists) as the advanced math requirement. In order to provide some flexibility, a student may take 21-259 (Calculus in Three Dimensions) and one 9-unit mathematics or statistics elective course to fulfill this requirement. Recommended courses include (but are not necessarily limited to): 21-260 (Differential Equations), 21-127 (Concepts of Mathematics), or 36-247 (Statistics for Laboratory Sciences). Less mathematically rigorous courses in statistics such as 36-201 (Statistical Reasoning and Practice) and 36-202 (Introduction to Statistical Methods) can NOT be used towards fulfillment of this requirement. You should verify your selection with your advisor before completing your mathematics elective.

### 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, for which the student has the necessary prerequisites, or by 03-231/232 Biochemistry I. 09-435, Independent Study in 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. 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 can be counted as free elective units. The Chemistry Department does not require technical electives.

## 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.

Biochemistry Option	Units
03-231/232 Biochemistry I	9
03-330 Genetics	9
03-344 Experimental Techniques in Biochemistry	12
xx-xxx Elective in Biochemistry*	

\*Elective may be 03-439, Introduction to Biophysics, 03-740, Advanced Biochemistry, 09-518, Bioorganic Chemistry: Nucleic Acids and Carbohydrates or 09-519, Bioorganic Chemistry: Peptides, Proteins and Combinatorial Chemistry

Polymer Science Option	Units
09-502 Organic Polymer Chemistry	9
09-509 Physical Chemistry of Macromolecules	9
39-802 Colloids, Polymers and Surfaces Laboratory II	9-12
09-xxx Elective in Polymer Science	9

Elective may be 09-445, Undergraduate Research (polymer project), or an upper level course in polymer science such as 09-545, Polymer Rheology

### Colloids, Polymers, and Surfaces Option (offered jointly with the Department of Chemical Engineering)

06-607 Physical Chemistry of Colloids and Surfaces	9
06-509 Physical Chemistry of Macromolecules	9
06-426 Experimental Colloid and Surface Science	9
06-466 Experimental Polymer Science	9

Materials Chemistry Option	Units
27-100 Materials in Engineering	12
27-201 The Structure of Materials	9

Two Elective Courses (from list below)	
27-202 Defects in Materials	(Fall, 9 units)
09-502 Organic Polymer Chemistry	(Spring, 9 units)
09-545 Polymer Rheology	(Fall, 9 units)
09-445 Undergraduate Research (in a materials area)	(Spring or Fall, 9 units)
09-509 Physical Chemistry of Macromolecules	(Fall, 9 units)
39-802 Colloids, Polymers, and Surfaces Lab	(Spring, 9 units)
09-511 Solid State Materials	(Spring, 9 units)
27-xxx Approved MSE Course	(Fall or Spring, 9 units)

Environmental Chemistry Option		Units
09-510	Introduction to Green Chemistry	9

Three Elective Courses (from the list below or other approved electives)

09-520	Global Atmospheric Chemistry	9
06-630	Atmospheric Chemistry, Air Pollution and Global Change	12
12-090	Technology and the Environment	9
12-251	Introduction to Environmental Engineering	9
12-651	Air Quality Engineering	9
12-655	Water Quality Engineering (Lab Recommended)	9
12-720	Water Resources Chemistry	12
19-420	Chemical Technologies, the Environment, and Society	9
19-422	Radiation, Health, and Policy	9

Only one of the 19-xxx courses can be applied to the Environmental Chemistry Option

Management Option		Units
70-101	Introduction to Business Management	9
70-122	Introduction to Accounting	9
70-364	Business Law (or 70-365 International Trade Law)	9
73-100	Principles of Economics	9

Computational Chemistry Option		Units
15-111	Intermediate/Advanced Programming	9
21-369	Numerical Methods	9
09-560	Computational Chemistry	12
xx-xxx	One Upper Level Computational Elective Course*	9

\*A list of approved courses for the elective for this option will be maintained and updated periodically by the Department. At the present time the list includes the following courses, but the Department will consider requests for other appropriate courses.

03-510	Computational Biology	12
03-511	Computational Molecular Biology and Genomics	9
03-512	Computational Methods for Biological Modeling and Simulation	9
33-241	Introduction to Computational Physics	9
15-211	Fundamental Data Structures and Algorithms	12
09-702	Statistical Mechanics and Dynamics	12
09-701	Quantum Chemistry I	12

Note: The Chemistry/Computational Chemistry Track (described later) requires the completion of the two upper level Computer Science courses 15-211 and 15-251, while in the Computational Chemistry Option, 15-111 and 21-369 are taken in place of these two courses. Since both 15-211 and 15-251 are prerequisites for higher level computer science courses, students in the Computational Chemistry Option should note that they are essentially blocked from taking additional courses in the Computer Science Department as senior computing electives. Students who complete 15-211 but not 15-251 may count 15-211 towards the Computational Chemistry Option as the required elective. Students pursuing the Computational Chemistry Option must complete course 15-100 as part of their MCS computing requirement.

A student who completes the recommended courses for any of these options will receive a certificate from the Department of Chemistry at Commencement as formal evidence of the accomplishment and a notation of this will be made on the student's transcript.

## 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 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 the Honors 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 graduate course, and that of the remaining electives required, at least two be undergraduate research (18 units) and one be 09-455, Honors Thesis (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 fall 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. To be accepted, students will be expected to have shown excellent performance in class work — normally at least a 3.2 average. An Honors Committee, comprised of the department's undergraduate advisors will monitor and evaluate the progress of the student's research project. A written and oral progress report to the Honors Committee is required in the fall of the senior year. 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. In April of the senior year, the Honors Committee will evaluate all theses and will require that each student participate in a public oral presentation or defense of the thesis before it approves the Honors degree. Students completing the B.S. with Departmental Honors in Chemistry will be eligible for MCS Research Honors as well.

## 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. Most commonly, applications are submitted during the second half of the sophomore year or during the junior year. 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 graduate course sequences in the junior year. Students can achieve this accelerated schedule through advanced placement and summer school.

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 of 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) as is participation in group seminars during the junior and senior years. Students must present their research at least twice at the Sigma Xi competition at Meeting of the Minds, the annual Carnegie Mellon undergraduate research symposium. In addition students must meet with the Honors 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 which work is complete and ready for publication.

A Thesis Committee will be formed to monitor the progress of each student. The committee shall consist of at least one member of the Honors Committee, 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, lecturer track or research track faculty. At the start of the spring semester of the senior year, 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. This will be 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 students are required to present their final oral defense of the project before the Thesis Committee. 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 Honors 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 figures. As for all M.S. degree 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.

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

The B.S./M.S. Honors degree requires the completion of five graduate level courses. These normally are 12-unit courses. 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 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

First Year		Units
03-121	Fall Introduction to Modern Biology	9
09-105	Introduction to Modern Chemistry	10
21-120	Differential and Integral Calculus	10
33-111	Physics for Science Students I	12
76-101	Interpretation and Argument	9
99-101	Computing @ Carnegie Mellon	3
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Students interested in majoring in chemistry should consider enrolling in the 3-unit lab course 09-101, Introduction to Experimental Chemistry, in the fall or spring semester of the freshman year. Although not required, the laboratory course is recommended for chemistry majors.

Spring		Units
09-106	Modern Chemistry II	10
21-122	Integration, Differential Equations and Approximation	10
33-112	Physics for Science Students II	12
15-100	Introductory/Intermediate Programming	10
xx-xxx	H&SS Distribution Course 1	9
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## Sophomore Year

Fall		Units
09-218	Modern Organic Chemistry I	10
09-231	Mathematical Methods for Chemists	9
09-221	Lab I: Introduction to Chemical Analysis	12
09-201	Undergraduate Seminar I	1
xx-xxx	H&SS Distribution Course 2	9
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Spring		Units
09-202	Undergraduate Seminar II	1
09-204	Professional Communication Skills in Chemistry	3
09-222	Lab II: Organic Synthesis and Analysis	12
09-220	Modern Organic Chemistry II	10
09-348	Inorganic Chemistry	10
xx-xxx	H&SS Distribution Course 3	9
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Summer  
10 weeks Honors Research recommended

## Junior Year

Fall		Units
09-301	Undergraduate Seminar III	1
09-321	Lab III: Organic Synthesis and Analysis	12
09-344	Physical Chemistry (Quantum)	9
09-331	Modern Analytical Instrumentation	9
09-445	Undergraduate Research	10
xx-xxx	H&SS/CFA Elective 1 (of 4)*	9

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Spring		Units
09-302	Undergraduate Seminar IV	1
09-322	Lab IV: Molecular Spectroscopy and Dynamics	12
09-445	Undergraduate Research	10
09-xxx	Graduate Chemistry Course (see notes on Honors B.S./M.S. electives)	12
09-345	Physical Chemistry (Thermo)	9
xx-xxx	H&SS/CFA Elective 2 (of 4)*	9

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## Summer

10 weeks Honors Research recommended

## Senior Year

Fall		Units
09-401	Undergraduate Seminar V	1
09-445	Undergraduate Research	10
09-xxx	Graduate Chemistry Course	12
09-xxx	Graduate Chemistry Course	12
xx-xxx	H&SS/CFA Elective 3 (Of 4)*	9

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Spring		Units
09-402	Undergraduate Seminar IV	3
09-455	Honors Thesis	15
09-xxx	Graduate Chemistry Course	12
09-xxx	Graduate Chemistry Course	12
xxx-xxx	H&SS/CFA Elective 4 (of 4)*	9

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\* Certain non-technical courses from Business Administration, Heinz School, and EPP also may be used. A listing of approved and non-approved courses for the H&SS/CFA electives is available at the following web site, [www.cmu.edu/mcs/education/edu\\_HSSFA.html](http://www.cmu.edu/mcs/education/edu_HSSFA.html), or see the Mellon College of Science section in this catalog for the Humanities and Social Sciences and Fine Arts Requirements. Accounting, finance, management, marketing, production, and statistics courses may NOT be used. Also, 70-100 (Introduction to Business) and 85-219 (Biological Foundations of Behavior) may NOT be used as electives in the H&SS/CFA category. If in doubt, check with your advisor.

## Distribution of Units for the B.S. with Honors/M.S. Degrees

Minimum Total Chemistry Units (250, See distribution below)

Required Chemistry Courses	Units
09-105 Introduction to Modern Chemistry**	10
09-106 Modern Chemistry II	10
09-204 Professional Communication Skills in Chemistry	3
09-219 Modern Organic Chemistry I ****	10
09-220 Modern Organic Chemistry II ****	10
09-231 Mathematical Methods for Chemists***	9
09-331 Modern Analytical Instrumentation	9
09-344 Physical Chemistry (Quantum)	9
09-345 Physical Chemistry (Thermo)	9
09-348 Inorganic Chemistry	10
09-221 Lab I: Introduction to Chemical Analysis	12
09-222 Lab II: Organic Synthesis and Analysis	12
09-321 Lab III: Molecular Design and Synthesis	12
09-322 Lab IV: Molecular Spectroscopy and Dynamics	12
09-xxx Chemistry Seminars	8
Undergraduate Research (2 summers also recommended)	30
Graduate chemistry courses (see notes on B.S./M.S. electives)	60
09-455 Honors Thesis	15

\*\* 09-107, Honors Chemistry, may be taken instead of 09-105.

\*\*\* 21-259, Calculus in Three Dimensions, and an additional Mathematics/Statistics Elective (see Notes on Electives in the B.S.

in Chemistry section) can be taken to fulfill the requirement for 09-231.

\*\*\*\* 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 in Chemistry, 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.

## Other Requirements

Biology	9
Computer Science	10
Mathematics	20
Physics	24
Humanities and Social Sciences or Fine Arts courses	72
Computing @ Carnegie Mellon	3

Minimum number of units required for degrees: 388

## B.S. in Chemistry/Computational Chemistry Track

The use of computers is ubiquitous in chemistry. Theoretical chemists run large "number-crunching" programs on supercomputers to understand and predict molecular structures, properties, and reactivity. Experimental physical chemists use computers to develop models to their data. Organic and inorganic chemists use computers to plan complex sequences of reactions and predict 3D structures and properties of molecules. Analytical chemists use microprocessors to control instruments and robots to perform repetitive processes.

Computer science will play a growing role in chemistry in the future, but very few people without a Ph.D. degree have the background in both fields that is necessary to make an impact. The B.S. in Chemistry/Computational Chemistry Track degree is a response to society's need for bachelor's degree scientists who can apply computational sophistication to the practical problems of science. It is simultaneously a response to the large number of students who want not merely to learn computer science, but to apply that expertise in a subject area that gives them an edge in the job market.

As the student builds expertise in chemistry by taking the full B.S. curriculum, elective courses are devoted to mathematics and computer science. This culminates with 09-560, Computational Chemistry, which affords an overview of the areas of overlap of computer science with chemistry.

The degree designation on the transcript of students who complete the requirements for this program is: B.S. in Chemistry/Computational Chemistry Track. The track is not noted on the diploma.

## Curriculum – B.S. in Chemistry/Computational Chemistry Track

## First Year

	Fall (Four Course Schedule)	Units
09-105	Introduction to Modern Chemistry	10
21-120	Differential and Integral Calculus	10
33-111	Physics I for Science Students	12
76-101	Interpretation and Argument	9
99-101	Computing @ Carnegie Mellon	3

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	Spring	Units
09-106	Modern Chemistry II	10
15-100	Introductory/Intermediate Programming	10
21-122	Integration, Differential Equations and Approximation	10
33-112	Physics II for Science Students	12
xx-xxx	H&SS Distribution Course 1	9

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## Sophomore Year

Fall		Units
09-201	Undergraduate Seminar I	1
09-219	Modern Organic Chemistry I	10
09-221	Lab I: Introduction to Chemical Analysis	12
21-127	Concepts of Mathematics	9
15-111	Intermediate/Advanced Programming	9
xx-xxx	H&SS Distribution Course 2	9

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Spring		
09-202	Undergraduate Seminar II	1
09-204	Professional Communication Skills in Chemistry	3
09-222	Lab II: Organic Synthesis and Analysis	12
09-220	Modern Organic Chemistry II	10
21-259	Calculus in Three Dimensions++	9
15-211	Fundamental Data Structures and Algorithms	12
xx-xxx	H&SS Distribution Course 3	9

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++ 09-231, Mathematical Methods for Chemists can be taken in lieu of 21-259. Note that 09-231 is offered only in the fall.

## Junior Year

Fall		
09-301	Undergraduate Seminar III®	1
09-321	Lab III: Molecular Design and Synthesis	12
09-344	Physical Chemistry (Quantum)	9
09-331	Modern Analytical Instrumentation	9
15-251	Great Theoretical Ideas in Computer Science	12
xx-xxx	H&SS/CFA Elective 1 (of 4)*	9

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Spring		
09-302	Undergraduate Seminar IV®	1
09-322	Lab IV: Molecular Spectroscopy and Dynamics	12
09-345	Physical Chemistry II (Thermo)	9
xx-xxx	Computing Elective	9
03-121	Modern Biology	9
xx-xxx	H&SS/CFA Elective 2 (of 4)*	9

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® Note that for this track 09-301 and 302 are not formally required, however you are encouraged to attend. These two courses are required for all other programs in chemistry.

## Senior Year

Fall		
09-401	Undergraduate Seminar V	1
09-560	Computational Chemistry**	12
09-xxx	Chemistry Elective	9
xx-xxx	Free Elective	9
xx-xxx	H&SS/CFA Elective 3 (of 4)*	9

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\*\* Computational chemistry may only be offered biannually and may move between the spring and fall semesters. You need to consult with your advisor as to the best time to schedule this course.

Spring		
09-402	Undergraduate Seminar VI	3
09-348	Inorganic Chemistry	10
xx-xxx	Computing Elective	9
xx-xxx	Free Elective	9
xx-xxx	H&SS/CFA Elective 4 (of 4)*	9

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\* Certain non-technical courses from Business Administration, Heinz School, and EPP also may be used. A listing of approved and non-approved courses for the H&SS/CFA electives is available at the following web site, [www.cmu.edu/mcs/education/edu\\_HSSFA.html](http://www.cmu.edu/mcs/education/edu_HSSFA.html), or see the Mellon College of Science section in this catalog for the Humanities and Social Sciences and Fine Arts Requirements. Accounting, finance, management, marketing, production, and statistics courses may NOT be used. Also, 70-100 (Introduction to Business) and 85-219 (Biological Foundations of Behavior) may NOT be used as electives in the H&SS/CFA category. If in doubt, check with your advisor.

Each student in the Computational Chemistry Track is required to complete two upper level mathematics and/or computer science electives. These may be chosen from the following list of courses. Others may be used with departmental approval.

Upper level Computing Courses		Units
15-212	Principles of Programming	12
15-312	Comparative Languages	9
15-411	Compiler Design	12
15-412	Operating Systems	12
15-413	Software Engineering	12
15-381	Artificial Intelligence: Representation and Problem Solving	9

15-384	Artificial Intelligence: Robotic Manipulation	9
15-385	Artificial Intelligence: Computer Vision	9
15-462	Computer Graphics (or equivalent)	9
15-xxx	Approved Elective	9

## Upper Level Mathematics Courses

21-369	Numerical Methods	9
21-228	Discrete Mathematics	9
21-301	Combinatorial Analysis (note 21-228 prerequisite)	9
21-xxx	Approved Elective	9

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

Minimum Total Chemistry Units (155; See distribution below)

Required Chemistry Courses		Units
09-105	Introduction to Modern Chemistry**	10
09-106	Modern Chemistry II	10
09-204	Professional Communication Skills in Chemistry	3
09-219	Modern Organic Chemistry I ****	10
09-220	Modern Organic Chemistry II ****	10
09-331	Modern Analytical Instrumentation	9
09-344	Physical Chemistry (Quantum)	9
09-345	Physical Chemistry (Thermo)	9
09-348	Inorganic Chemistry	10
09-221	Lab I: Introduction to Chemical Analysis	12
09-222	Lab II: Organic Synthesis and Analysis	12
09-321	Lab III: Molecular Design and Synthesis	12
09-322	Lab IV: Molecular Spectroscopy and Dynamics	12
09-560	Computational Chemistry	12
09-xxx	Chemistry Seminars	6
09-xxx	Chemistry Elective	9

\*\* 09-107, Honors Chemistry, may be taken instead of 09-105.

\*\*\*\* 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 in Chemistry, 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.

## Other Requirements

Biology	9
Computer Science	43
Mathematics	38
Physics	24
Humanities and Social Sciences or Fine Arts courses	72
Computing or Math Electives	18
Computing @ Carnegie Mellon	3

Minimum number of units for the degree: 362

The above B.S. curriculum recommends an average course load of 37-55 units/semester. The total units will 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.

## 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. It is not possible to combine the B.A. degree in chemistry with an additional B.A. degree in another department in MCS (e.g. Biological Sciences). 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: 09-219 (Modern Organic Chemistry I) and 09-321 (Laboratory III: Molecular Design and Synthesis); and the spring-only courses: 09-214 (Physical Chemistry), 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 vice versa) due to a departmental curriculum change.

## Curriculum – B.A. in Chemistry

### First Year

Fall (Four Course Schedule)		Units
09-105	Introduction to Modern Chemistry	10
21-120	Differential and Integral Calculus	10
33-111	Physics I for Science Students	12
76-101	Interpretation and Argument	9
99-101	Computing @ Carnegie Mellon	3
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Students interested in majoring in chemistry should consider enrolling in the 3-unit lab course 09-101, Introduction to Experimental Chemistry, in the fall or spring semester of the freshman year. Although not required, the laboratory course is recommended for chemistry majors.

Spring		Units
09-106	Modern Chemistry II	10
15-100	Introductory/Intermediate Programming	10
21-122	Integration, Differential Equations and Approximation	10
33-112	Physics II for Science Students	12
xx-xxx	H&SS Distribution Course 1	9
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### Sophomore Year

Fall		Units
09-201	Undergraduate Seminar I	1
09-219	Modern Organic Chemistry I	10
09-221	Lab I: Introduction to Chemical Analysis	12
xx-xxx	Free Elective	9
xx-xxx	H&SS Distribution Course 2	9
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Spring		Units
09-202	Undergraduate Seminar II	1
09-204	Professional Communication Skills in Chemistry	3
09-220	Modern Organic Chemistry II	10
09-222	Lab II: Organic Synthesis and Analysis	12
09-214	Physical Chemistry	9
xx-xxx	H&SS Distribution Course 3	9
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### Junior Year

Fall		Units
09-301	Undergraduate Seminar III	1
09-321	Lab III: Molecular Design and Synthesis	12
03-121	Modern Biology	9
09-xxx	Chemistry Elective	9
xx-xxx	Free Elective	9
xx-xxx	H&SS/CFA Elective 1 (of 4)*	9
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Spring		Units
09-302	Undergraduate Seminar IV	1
09-348	Inorganic Chemistry	10
09-xxx	Chemistry Elective	9
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9
xx-xxx	H&SS/CFA Elective 2 (of 4)*	9
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### Senior Year

Fall		Units
09-401	Undergraduate Seminar V	1
xx-xxx	Free Electives	36
xx-xxx	H&SS/CFA Elective 3 (of 4)*	9
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Spring		Units
09-402	Undergraduate Seminar VI	3
xx-xxx	Free Electives	28
xx-xxx	H&SS/CFA Elective 4 (of 4)*	9
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\* Certain non-technical courses from Business Administration, Heinz School, and EPP also may be used. A listing of approved and non-approved courses for the H&SS/CFA electives is available at the following web site, [www.cmu.edu/mcs/education/edu\\_HSSFA.html](http://www.cmu.edu/mcs/education/edu_HSSFA.html), or see the Mellon College of Science section in this catalog for the Humanities and Social Sciences and Fine Arts Requirements. Accounting, finance, management, marketing, production, and statistics courses may NOT be used. Also, 70-100 (Introduction to Business) and 85-219 (Biological Foundations of Behavior) may NOT be used as electives in the H&SS/CFA category. If in doubt, check with your advisor.

## Distribution of Units for the B.A. Degree

Minimum Total Chemistry Units (124; See distribution below)

Required Chemistry Courses	Units	
09-105	Introduction to Modern Chemistry**	10
09-106	Modern Chemistry II	10
09-204	Professional Communication Skills in Chemistry	3
09-219	Modern Organic Chemistry I ****	10
09-220	Modern Organic Chemistry II ****	10
09-214	Physical Chemistry (or 09-344 or 09-345)	9
09-348	Inorganic Chemistry	10
09-221	Lab I: Introduction to Chemical Analysis	12
09-222	Lab II: Organic Synthesis and Analysis	12
09-321	Lab III: Molecular Design and Synthesis	12
09-xxx	Chemistry Seminars	8
09-xxx	Chemistry Electives	18

\*\* 09-107, Honors Chemistry, may be taken instead of 09-105

\*\*\*\* 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 in Chemistry, 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.

### Other Requirements

Biology (03-121)	9
Computer Science (15-100)	10
Mathematics (21-120 and 21-122)	20
Physics (33-111(I) and 33-112(II))	24
Humanities and Social Sciences or Fine Arts courses	72
Free Electives	100
Computing @ Carnegie Mellon	3

Minimum number of units for the degree: 360

The above B.A. curriculum recommends an average course load of 40-51 units/semester. The total units will 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.

## 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, or by 03-231/232 Biochemistry I. 09-435, Independent Study in 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. 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 can be counted as free elective units. The Chemistry Department does not require technical electives.

## Requirements for a Minor in Chemistry

In order for a student to receive the added designation "...with 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 in the department office, DH 1317 or from the MCS undergraduate web page.

### A. Four Required Core Courses

- 09-106 Modern Chemistry II
- 09-221 Laboratory I: Introduction to Chemical Analysis
- 09-217 Organic Chemistry I
- Choice of one of the following courses\*:
  - 09-348 Inorganic Chemistry
  - 09-344 Physical Chemistry (Quantum)
  - 09-345 Physical Chemistry (Thermo)
  - 09-347 Advanced Physical Chemistry\*\*
  - 09-214 Physical Chemistry

\*Courses in this group that are not used to satisfy Part A core courses (section 4) may be used to 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 this course is only open to students majoring in chemical engineering.

### B. Two Elective Courses from the following list.

- 09-344 Physical Chemistry (Quantum) or
- 09-214 Physical Chemistry
- 09-345 Physical Chemistry (Thermo)
- 09-348 Inorganic Chemistry
- 09-222 Laboratory II: Organic Synthesis and Analysis
- 09-218 Organic Chemistry II
- 03-231/232 Biochemistry I
- 09-xxx Approved Upper Level Chemistry Course

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 09-214, 03-231 (or -232), 09-222, or 09-218 toward the elective courses for the minor in chemistry. Chemical engineering majors can not count 03-231 (or 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 courses 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, and 09-435, Independent Study in Chemistry, cannot be used for the minor.

## Other Programs

As part of the undergraduate degree program, chemistry majors have the opportunity to pursue various special programs at Carnegie Mellon to enrich their academic experience. These include but are not limited to: programs with the College of Fine Arts, Humanities and Social Sciences, the H. John Heinz School of Public Policy and Management; Interdisciplinary Majors and Minors including Health Care Policy and Management. For more details, see the Tailoring Your Education portion of the Mellon College of Science section in this catalog.

## Faculty

CATALINA ACHIM, Associate Professor of Chemistry — Ph.D., Carnegie Mellon; Carnegie Mellon, 2001 —.

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GARY D. PATTERSON, Professor of Chemistry — Ph.D., Stanford University; Carnegie Mellon, 1984—.

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#### Courtesy

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