DEPARTMENT OF CHEMISTRY UNDERGRADUATE HANDBOOK 2023-2024

The goal of this handbook is to introduce undergraduate students to the Chemistry Department and provide them with detailed information about the Chemistry Major at Yale.

This handbook should be used alongside other resources such as:

i) The Yale College Program of Study (YCPS) for the Academic Year 2023-2024, which contains brief descriptions of all Undergraduate Chemistry Courses. (http://catalog.yale.edu/ycps/subjects-of-instruction/chemistry/)

ii) The Yale Chemistry Department Website (https://chem.yale.edu/academics/undergraduate-studies).

The Chemistry (CHEM) Major is offered by the Department of Chemistry.

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I. Introduction

Chemistry has been responsible for some of the most significant improvements in our quality of life over the last century. The discovery of antibiotics and other pharmaceuticals, the advent of computers, and the development of industrial methods such as the Haber-Bosch process to produce fertilizer, all have required fundamental advances in chemistry and have had profound impacts on society. In the next century, it is likely that chemistry will play a central role in the development of alternative-energy vectors to replace fossil fuels, the realization of practical quantum computers, the discovery of new methods to treat and prevent diseases, and the adoption of more sustainable industrial processes. The Chemistry Major at Yale provides students with the technical foundation to both appreciate the scientific basis for previous discoveries and develop the fundamental skills required to make future breakthroughs.

Under the tutelage of world-leading researchers, students are exposed to a broad range of topics in chemistry. After completion of the prerequisites, core classes in Organic, Inorganic, and Physical Chemistry are supplemented by advanced elective classes in more specialized areas such as Chemical Biology, Quantum Chemistry, and Organometallic Chemistry. The development of technical skills through lecture classes is complemented with hands-on experience in state-of-the-art chemistry laboratories. Many students also perform independent laboratory research under the guidance of a faculty mentor. This rigorous training prepares students for professional careers in a diverse array of fields by teaching them how to apply the scientific method, providing them with skills in quantitative reasoning, and exposing them to scientific research. After completing their degree, Chemistry Majors often pursue graduate work in chemistry, biochemistry, or health-related disciplines, but also find their broad scientific training beneficial in fields such as technology policy, business management, and law. Chemistry is an especially appropriate major for students interested in energy research or policy and the environment.

The teaching and research facilities in Chemistry include the iconic Sterling Chemistry Laboratory (built in 1923) which encompasses a new state-of-the-art undergraduate teaching center, the completely reworked Kline Chemistry Laboratory, and the cutting-edge Class of 1954 Chemistry Research Building, in addition to interdisciplinary research laboratories on Yale's West Campus. The Chemistry Department consists of approximately 25 research-active faculty, 4 full-time lecturers whose primary focus is undergraduate teaching, 70 postdoctoral fellows, 180 graduate students, and roughly 60 Chemistry Majors, all of whom work and study in these buildings. The quality and breadth of expertise in the Yale Chemistry community, which also includes faculty having joint appointments in Cell Biology, Molecular, Cellular, and Developmental Biology (MCDB), Molecular Biophysics and Biochemistry (MB&B), and Physics (PHYS), has made Yale a premier center in Chemistry for both students and faculty.

II. What Can Being a Chemistry Major Do for Me?

The successful completion of a Chemistry Major at Yale prepares students for a future career in a wide range of professions, including medicine, the pharmaceutical industry, and chemical research, as well as various aspects of science-oriented writing, policy-making, teaching, and consulting. Central themes that students are exposed to throughout the Major are designed to develop expertise in quantitative reasoning, expand knowledge of basic chemical concepts, hone laboratory skills, and foster an appreciation for the important role of science in society. Advanced electives allow students to specialize in specific areas of chemistry, such as Physical, Theoretical, Inorganic, or Organic Chemistry, or Chemical Biology. This rigorous training prepares students for the next stage of their careers, and Chemistry Majors have a high rate of acceptance at medical and graduate schools.

Undergraduate Chemistry Majors at Yale are a valued part of the Yale Chemistry Community. Along with events organized exclusively for Majors, they are invited to various Departmental activities such as the annual Holiday Party and the Yale Chemistry Symposium[1]. This allows Chemistry Majors to build camaraderie among themselves and to interact actively with other members of the Department. In addition, Chemistry Majors engaged in independent research often develop close relationships with other group members. The connections that are facilitated by events within the Chemistry Department can be both academically and personally valuable for Chemistry Majors for many years into the future.

[1] The Yale Chemistry Symposium is a one-day symposium where graduate students give talks describing their research. There is also a keynote address from a member of the Yale Chemistry Faculty. This year the Symposium will be held on Friday the 25th of August. More information will be available on the Yale Chemistry website.

III. Chemistry Degrees and Courses

Yale undergraduates can select from four different degrees in Chemistry: B.A., B.S., B.S. (Intensive), and B.S./M.S. These differ primarily in the number of required courses and also in the manner in which the senior requirement is completed. The B.A. requires the fewest number of classes, while the B.S./M.S. requires the most. All four degrees require students to complete the appropriate number of courses (see Section IV for detailed information about the exact requirements for each degree) from the following categories:

(i) *Prerequisites to the Major.* These courses provide students with the necessary background for studying chemistry. For all degrees, this includes courses in Physics and Mathematics, as well as two semesters of General Chemistry Lecture and Laboratory. If a student has a suitable background, in some cases the DUS will waive a prerequisite course. For example, students who start in Organic Chemistry for First Year Students, do not have to take the General Chemistry Lecture or Laboratory sequences at Yale.

(ii) *Core Courses.* Courses in Organic, Inorganic, and Physical Chemistry are required courses for the Chemistry Major.

(iii) *Advanced Lecture Courses.* These lecture courses cover material beyond the standard Organic, Inorganic, and Physical Chemistry curriculum. They allow students to specialize in specific areas, for example Organic or Inorganic Chemistry, and learn about more advanced topics in Chemistry such as Quantum Chemistry or Chemical Biology. For Chemistry courses, advanced lecture courses typically are numbered 410 or above. In some cases, courses offered outside the Chemistry Department, such as MB&B 300 (Principles of Biochemistry I) or PHYS 448 (Solid State Physics I), will be counted as advanced lecture courses towards the Chemistry Major. Each semester, the DUS provides students with a list of courses in the Chemistry Department that are permitted to count as advanced lecture courses. Students who wish to complete an advanced lecture course outside the Chemistry Department should contact the DUS for permission prior to formally enrolling in the course. All advanced chemistry lecture courses are half-semester (0.5 credit) courses.

(iv) *Advanced Laboratory Courses.* These are intensive (1.0 credit) laboratory courses which teach students specialized skills beyond the core curriculum. At least one advanced laboratory course is required for all degrees.

(v) *Senior Requirement.* All degrees require a senior essay. The pathway for completing the senior essay varies depending on the degree type. Specific information about the senior requirement can be found in Section VI.

In some cases, courses that count as a core course for one degree will count as an advanced lecture or laboratory course for another degree. For example, CHEM 333 (Physical Chemistry with Applications in the Physical Sciences II) is a core course for the B.S., B.S. (Intensive), and B.S./M.S. degrees but is considered an advanced lecture course for the B.A. degree.

Students should choose among the four available degree tracks according to their career objectives. A brief description of the type of student for which each degree is designed is provided below.

(i) **B.A.:** The B.A. is typically for students who have an interest in chemistry, but intend to pursue a major or career in another discipline. In these cases, a solid chemical training would be an asset to the student's other major or career. For example, training in chemistry could be beneficial to students who wish to pursue a major or career in areas such as technology policy, economics, or the environment. The B.A. degree is not appropriate for students who wish to pursue a Ph.D. in chemistry, and typically is completed by students who also are majoring in another discipline.

(ii) **B.S.:** The B.S. is intended to prepare students for graduate study in chemistry or a related field, while permitting extensive exploration of other disciplines. Research is not required as part of the B.S. degree.

(iii) **B.S. (Intensive):** The B.S. (Intensive) prepares students for further careers in the sciences in a similar fashion to a B.S.; however, it offers a more rigorous program of study that requires an extra class in Physics, an extra advanced lecture or laboratory course, and, most importantly, a compulsory research component. Most students decide between the B.S. and B.S. (Intensive) degree based on how many classes they wish to pursue outside of the Chemistry Major, as the choice does not affect prospects after graduation strongly.

(iv) **B.S./M.S.:** The B.S./M.S. is designed for students whose advanced preparation qualifies them for graduate-level work in the third and fourth years of their undergraduate degree. It requires the completion of eight graduate-level courses in Chemistry. Most years, there are only one or two Chemistry Majors for which this degree is suitable and sometimes it is not suitable for any Chemistry Major. A B.S./M.S. degree is of little value to students who intend to pursue a Ph.D. in Chemistry, as an M.S. is awarded as part of a doctoral program at most institutions. There also is an opportunity cost associated with taking the large number of advanced chemistry classes required for the B.S./M.S. degree, as students can take fewer classes in other areas. Typically, the B.S./M.S. degree is most suitable for students who wish to pursue a career in policy or consulting and are not intending to complete any additional formal training in Chemistry. The B.S./M.S. degree includes a large research component. For more information on the B.S./M.S. degree see Section VII.

IV. Chemistry Roadmaps

<table>
<tr><th></th><th colspan="4">Chemistry</th></tr>
<tr><td>Degrees Offered</td><td>BA Chemistry</td><td>BS Chemistry</td><td>BS Chemistry (Intensive Major)</td><td>BS/MS Chemistry</td></tr>
<tr><td rowspan="3">Prerequisites for entering the major</td><td colspan="4">CHEM 161 and 165 or CHEM 163 and 167;
CHEM 135L and 136L</td></tr>
<tr><td colspan="4">MATH 115, MATH 120, or ENAS 151</td></tr>
<tr><td colspan="4">PHYS 170, 180, 200 or 260 or equivalents in advanced placement</td></tr>
<tr><td rowspan="6">Requirements for each degree</td><td>Total of 10 credits</td><td>Total of 13 credits</td><td>Total of 15 credits</td><td>Intensive
+ 4 credits from grad courses</td></tr>
<tr><td colspan="3">2 Semesters Organic Chemistry (with Labs)
CHEM 174 or 220 and CHEM 175, 221, or 230. CHEM 222L and 223L</td><td>Application by end of 5th term</td></tr>
<tr><td>Physical Chemistry (CHEM 332 or 328)</td><td colspan="2">2 Physical Chemistry courses and 1 Lab
(CHEM 332 or 328; 333; 330L)</td><td>CHEM 490 during 5th/6th term</td></tr>
<tr><td colspan="3">Inorganic Chemistry
CHEM 252</td><td>Research between Jr/Sr year</td></tr>
<tr><td colspan="2">N/A</td><td>PHYS 171, 181, 201, or 261</td><td rowspan="2">Advanced credits include 8 grad courses (4 credits applied to the B.S.)</td></tr>
<tr><td>4 credits of Adv. electives
at least 1 credit of Chem lecture & 1 credit of lab</td><td>4 credits of Adv. electives
at least 1 credit of Chem lecture & 1 credit of lab</td><td>5 credits of Adv. electives
at least 2 credits of Chem lecture & 1 credit of lab</td></tr>
<tr><td>Senior Requirements</td><td>CHEM 400</td><td>CHEM 490 (2 semesters) or CHEM 400 + 1 additional credit of advanced courses</td><td>CHEM 490 (2 semesters)</td><td>4 Research Semesters</td></tr>
<tr><td>Substitutions</td><td colspan="3">Up to 2 credits of relevant science courses in other departments</td><td>N/A</td></tr>
</table>

Updated August 2021

Four possible paths through the Chemistry Major:

Possible BA Sequence

	Fall	*Spring*
Year 1	CHEM 161, 134L, & MATH pre-req	CHEM 165, 136L, & MATH pre-req
Year 2	CHEM 220, 222L, & PHYS pre-req	CHEM 221, 223L, & 252
Year 3	CHEM 332	Advanced Lab & 1 Elective
Year 4	CHEM 400 & 1 Elective	1 Elective

Possible BS Sequence

	Fall	*Spring*
Year 1	CHEM 161, 134L, & MATH pre-req	CHEM 165, 136L, & MATH pre-req
Year 2	CHEM 220, 222L, & Phys pre-req	CHEM 221 & 223L
Year 3	CHEM 332 & 330L	CHEM 333, 252, & Advanced Lab
Year 4	CHEM 490 & 2 Electives	CHEM 490 & 1 Elective

Possible BS Intensive Sequence

	Fall	*Spring*
Year 1	CHEM 163, 134L, & MATH pre-req	CHEM 167, 136L, & MATH pre-req
Year 2	CHEM 220, 222L, & PHYS pre-req	CHEM 221, 223L, 252, & PHYS pre-req
Year 3	CHEM 332 & 330L	CHEM 333, Advanced Lab, & 1 Elective
Year 4	CHEM 490 & 2 Electives	CHEM 490 & 1 Elective

Possible BS/MS Sequence

	Fall	*Spring*
Year 1	CHEM 174, 222L, MATH & PHYS pre-req	CHEM 175, 223L, MATH & PHYS pre-req
Year 2	CHEM 330L & 332	CHEM 333, 252, & Advanced Lab
Year 3	CHEM 490 & 2 Electives	CHEM 490 & 2 Electives
Year 4	CHEM 990 & 2 Electives	CHEM 990 & 2 Electives

V. First Year Chemistry

First Year (General) Chemistry is a prerequisite to complete a Chemistry Major. The majority of students begin their studies in Chemistry at Yale by completing the General Chemistry sequence: either CHEM 161 and 165, General Chemistry I and II, or CHEM 163 and 167, Advanced University Chemistry I and II. Through the placement process (described below) the Chemistry Department provides advice to students on which flavor of General Chemistry is most suitable. Typically, students completing CHEM 161 may be taking chemistry for the first time or perhaps took chemistry as a high-school sophomore. Students enrolled in CHEM 163 will have more recently completed a year or two of chemistry in high school or may even have taken AP chemistry but not fully mastered the subject at that level, although motivated students may have last taken chemistry as a high-school sophomore if they have a strong math and physics background. Regardless of whether a student completes the CHEM 161/165 or CHEM 163/167 sequence, they are required to take the same General Chemistry Laboratories, CHEM 134L, General Chemistry Laboratory I, and CHEM 136L, General Chemistry Laboratory II. Prospective majors who plan to start in General Chemistry are encouraged to begin their studies in chemistry in their first year at Yale to ensure they can complete all of the requirements for the Chemistry Major, especially if they intend to receive a B.S. Nevertheless, it is possible to complete the B.S. in as little as six terms if a student has advanced placement (see below).

Students with a sufficiently strong background in chemistry may initiate their studies with courses in Organic or Physical Chemistry after demonstrating proficiency on the Department's placement examination. Students who have obtained a score of 5 on the AP chemistry exam are especially encouraged to take the placement exam and start in CHEM 174, Organic Chemistry for First-Year Students, CHEM 220, Organic Chemistry I, or CHEM 332, Physical Chemistry I. In particular, CHEM 174 is offered exclusively for first-year students and provides students with an opportunity to build lasting connections with their peers, while learning organic chemistry with a smaller group of students. Although students sometimes elect to complete CHEM 220 rather than CHEM 174 because of scheduling issues, the Department strongly recommends CHEM 174. Enrollment in CHEM 332 is recommended for students with a strong background in mathematics. Students who complete CHEM 174, CHEM 220, or CHEM 332 in their first year do not need to complete any General Chemistry Lecture or Laboratory courses (these prerequisites are assumed to have been fulfilled as gauged by performance on the placement examination).

As described briefly below, the procedure used to select an appropriate level of Chemistry for each incoming (first-year) student is based upon information supplied during matriculation as well as an optional in-house placement examination.

1. Placement in General Chemistry Courses

The Chemistry Department reviews the preparation of all first-year students prior to the beginning of the fall term, using test scores, admission records, and other information supplied by students through the High-School Math and Science Survey. Incoming students should complete this survey during the summer before matriculation. In particular, the Department determines the appropriate General Chemistry lecture course, either CHEM 161 or 163, for every entering first-year student. Students will be able to view their initial placement in early August at the "Course Placement" site on Canvas@Yale. Students who wish to take a more advanced course than their initial placement recommends should plan to take the on-campus placement examination.

2. Placement in Higher-Level Courses

First-year students wishing to engage Organic or Physical Chemistry (CHEM 174, 220, or 332), as well as those wishing to take a higher-level course in General Chemistry than initially assigned by the procedures described above, are required to take a placement examination. Details about how to complete the placement exam are available on the Chemistry Department website.

VI. The Senior Requirement

All Chemistry Majors must complete the senior requirement, which takes the form of a capstone essay. However, the path for writing the senior essay varies depending on the type of degree being pursued. A summary of the different ways to complete the senior requirement for each type of degree is provided below.

B.A. Degree

The only way to fulfil the senior requirement is through completion of CHEM 400, Current Chemistry Seminar, which is a seminar course offered exclusively in the Fall semester of each academic year. It is designed to engage students in the Chemistry research-seminar program by providing requisite scientific guidance and a forum for directed discussion. Students write a final paper as part of this course, which counts as their senior essay. Only students in their Senior year are permitted to enroll in CHEM 400.

B.S. Degree

The senior requirement can be fulfilled in two ways, depending on student preferences:

(i) Through the completion of two semesters (Fall & Spring) of CHEM 490, Independent Research in Chemistry, during the Senior year[2]. In this course students perform research with an individual faculty member. At the conclusion of their second semester of CHEM 490, students must write a report (their senior essay) describing their research efforts and must discuss their work publicly in the form of a poster presentation. Both of these activities are coordinated by the Instructor of CHEM 490. More information about independent research and CHEM 490 can be found in Section VIII.

(ii) Through the completion of CHEM 400, Current Chemistry Seminar, and one additional course credit of advanced chemistry lecture or laboratory courses. The final paper written as part of CHEM 400 is considered to be the senior essay.

B.S. (Intensive) Degree

The only way for students to fulfill the senior requirement is through the completion of two semesters (Fall & Spring) CHEM 490, Independent Research in Chemistry, during the Senior year[2]. In this course students perform research with an individual faculty member. At the conclusion of their second semester of CHEM 490, students must write a report (their senior essay) describing their research efforts and must discuss their work publicly in the form of a poster presentation. Both of these activities are coordinated by the Instructor of CHEM 490. More information about independent research and CHEM 490 can be found in Section VIII.

B.S./M.S.

The senior requirement is fulfilled in the same manner as for the B.S. (Intensive) Degree, but students must complete their written essay and poster presentation during the Junior year. To do this, permission is required from the Chemistry DUS.

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[2]In rare circumstances, which must be approved by the Chemistry DUS, students may be able to complete one semester of CHEM 490 in their Junior year and one in their Senior year.

VII. The Combined B.S./M.S. Degree

Exceptionally well-prepared students may complete a course of study leading to the simultaneous award of the B.S. and M.S. degrees after eight terms of enrollment. Formal application for admission to this Yale program must be made no later than the last day of classes in the fifth term of enrollment. The formal application process involves providing the following information:

(i) Evidence of eligibility for the B.S./M.S. degree through the submission of an academic transcript. To be eligible for enrollment applicants must have achieved at least two-thirds A or A⁻ grades in all of their course credits as well as in all of the course credits directly relating to the major, including prerequisites, by the end of their fifth term.

(ii) A letter outlining the reasons why a simultaneous degree is being pursued.

(iii) A detailed plan for completing the program requirements (see below).

The application for admission to the combined B.S./M.S. degree program first should be submitted to the Chemistry DUS for approval by the Chemistry Department. If the Department acts favorably on the student's application, it is forwarded with the formal approval of the Chemistry DUS and DGS to the Director of Academic and Educational Affairs in the Yale College Dean's Office, where a joint committee of Yale College and the Yale Graduate School considers the nomination and notifies the student of acceptance into the program.

Even though the formal application is not due until the last day of classes in the fifth term of enrollment, in practice students interested in the B.S./M.S. degree should consult with the Chemistry DUS in their fourth term (or earlier) of enrollment.

The basic requirements for a B.S./M.S. degree in Chemistry are as follows:

(i) The completion of all requirements for the B.S. (Intensive) degree, including the senior requirement, which typically is accomplished in the fifth and sixth terms of enrollment. In addition, the introductory physics requirement must be fulfilled with PHYS 200 and 201 or 260 and 261. Subject to approval by the Chemistry DUS, a term course in physics numbered 400 or higher may be substituted for the introductory sequence.

(ii) The completion of eight (8) graduate credits in chemistry, four (4) of which can also be counted toward the B.S. (Intensive) degree. Students must earn grades of A in at least two of their graduate-level term courses (or in one yearlong course) and have at least a B average in other graduate-level courses.

(iii) Four (4) terms of independent research in chemistry supervised by a faculty member are required. Typically, a student completes two terms in their Junior year through CHEM 490, Independent Research in Chemistry, and two terms in their Senior year through CHEM 990, Graduate Chemistry Research. Additionally, students are required to perform independent research with the same faculty member with whom they are completing CHEM 490 and CHEM 990 in the summer between their Junior and Senior years. Normally, the faculty member involved is a member of the Chemistry Department; however, subject to approval by the Chemistry DUS, research can be performed with a faculty member outside the Department.

(iv) At the end of their eighth semester, students are required to write a thesis summarizing their research activities. This document must be written under the guidance of the faculty member supervising the student's independent research and it must be submitted on the final day of classes (of the student's eighth semester of enrollment) to their research adviser. The thesis should be no shorter than twenty-five pages (double-spaced, twelve-point font, excluding figures, tables, and bibliography) and normally should contain the following sections: Introduction, Results and Discussion, Summary and Conclusions, Research Methods, and Bibliography. Students in the B.S./M.S. program must discuss their work in the form of a public poster presentation at the end of their sixth semester (to fulfill requirements of the intensive B.S. degree) and a public oral presentation at the end of their eighth semester (to fulfill requirements of the M.S. degree). These poster (for CHEM 490) and oral (for CHEM 990) presentations both are coordinated by the instructor of CHEM 490.

VIII. Independent Research

Research is required for several Chemistry Degrees and is essential for those undergraduates wishing to obtain a Ph.D. in Chemistry after graduation. The Chemistry Department provides extensive opportunities for its Majors to perform independent research under the supervision of a faculty member. Research activities span all areas of chemistry, as well as related fields such as Biochemistry and Chemical Physics. All interested students are encouraged to participate in research by working in laboratories for academic credit and/or experience. Financial support may be available in some cases, but students being paid will not receive course credit. A list of faculty associated with the Chemistry Department is provided in Section XIV.

Setting up a research appointment is done using an informal process in which the student contacts faculty members directly regarding possible research opportunities in their research group. The standard protocol is to request a meeting via e-mail, with an updated CV or resume being attached to provide the faculty member with relevant background information (courses taken, prior research experiences, *etc.*). It is best to discuss research opportunities with several faculty members before choosing a group to join, because groups differ not only by research topic but also by size and style. Prior to making a decision, students should gather information on each faculty member's philosophy about undergraduate research and on their expectations for undergraduate researchers, either by talking to the faculty member directly or to members of their research group. Senior undergraduates also may be able to provide advice about research in the Chemistry Department. Typically, a student should contact supervisors approximately three months before they intend to commence research.

There is no set time when Chemistry Majors should begin independent research. Some start in the summer after their first year (see Section VIII below on Summer research), whereas others wait until their Junior year. However, students who intend to complete CHEM 490 should have some research experience prior to their Senior year. In general, it takes some time to become accustomed to research methods in a given group, and thus it is possible to achieve more by continuing research in the same group than by switching between many research groups.

All students engaging in research activities are required to complete safety training as instructed by their faculty mentor prior to initiating any laboratory work. Additionally, undergraduate researchers must fill out and submit the appropriate form notifying the Chemistry Department that they are conducting research (see Section XV).

Research Courses

The Chemistry Department offers two different courses focused on research:

CHEM 480 (*Introduction to Independent Research in Chemistry*)

Declared Sophomore and Junior Chemistry Majors may elect to complete CHEM 480. Here, students perform at least ten hours of independent research per week with an individual faculty member and write a report about their work at the conclusion of the term. CHEM 480 can be taken multiple times for credit and is designated as a Pass/Fail course governed by Yale College's "P/F with report" policy. A student who passes CHEM 480 will have the mark of "P" entered on their transcript once the course instructor submits an independent-study form with an evaluation of their performance (this report can be viewed by the student). Failure in the course will result in a recorded grade of "F". The completion of CHEM 480 does not satisfy any course requirements for the Chemistry Major.

CHEM 490 (*Independent Research in Chemistry*)

Two semesters of CHEM 490 are needed to satisfy the senior requirement for the B.S. (Intensive) degree. Students engaging the B.S. degree also may elect to fulfill the senior requirement by completing two semesters of CHEM 490 in conjunction with the senior essay. CHEM 490 students conduct independent research with an individual faculty member for at least ten hours per week, with additional mandatory class meetings (typically one hour per week) addressing issues of essential laboratory safety, ethics in science, online literature searching, oral presentation skills, and effective scientific writing. If a Chemistry Major wishes to perform research with a faculty member who does not have an appointment in the Chemistry Department, their proposed research plan needs to be evaluated by the Chemistry DUS (prior to the start of research) to ensure that it is suitable for CHEM 490. At the end of the second semester of CHEM 490, students are expected to submit a report describing their research and to discuss their research publicly in the form of a poster presentation. Each semester students will receive a letter grade from the instructor of CHEM 490 that takes into account the grade recommendation forwarded by their research mentor. Chemistry Majors in the B.S./M.S. degree program complete CHEM 490 in their Junior year, whereas all other students only can enroll in their Senior year, unless there are exceptional circumstances (see above).

Summer Research

Chemistry Majors also can perform research with a faculty member during the summer months, which allows them to work full-time on a specific project. Summer research enables students to continue activities that were initiated during the previous academic year or to begin projects that will be continued during the following academic year. Sometimes the faculty member has grant funds that can support students during the summer. More commonly financial support is provided by the Yale College Deans Office, with further information about such summer-fellowship programs found at the following website: https://science.yalecollege.yale.edu/yale-undergraduate-research/fellowship-grants/yale-college-deans-research-fellowship.

Applications for Summer research funding normally are due at the end of February, and interested students should contact a member of the Yale Chemistry Department Faculty in January (or preferably sooner) about summer-research opportunities. Academic credit is not granted for summer research.

Summer research at other institutions (including those outside the United States) is possible through several programs. More information can be found at the following websites:

https://yalecollege.yale.edu/get-know-yale-college/directory/fellowships-funding-directory

http://science.yalecollege.yale.edu/yale-science-engineering-research/fellowship-grants

Additional information about funding for summer research can be found in Section XIII.

IX. Advising for Chemistry Majors

The Chemistry Department is committed to providing advice for students about which classes are appropriate for them and how to achieve their goals after graduation. Once a student has declared themselves to be a Chemistry Major, they are assigned a faculty advisor. Students retain the same faculty advisor until they graduate, thus enabling them to develop an ongoing rapport. Students typically meet with their advisor during the first week of each semester to receive general career advice. More informal meetings can be scheduled as required throughout the semester. Advisors typically do not sign course schedules, but do provide more holistic guidance about courses and careers. Chemistry Majors should contact the Chemistry Academic Support Assistants to be assigned an advisor if this is not done automatically.

At the start of each semester Chemistry Majors are required to have their course schedule signed by the Chemistry DUS. For Junior and Senior Chemistry Majors the DUS will have provided advice about required courses prior to the start of semester. Students following this advice can submit their schedule to the Chemistry Undergraduate Registrar for the DUS to review and approve. If there is a problem with the schedule or further advice is required, a meeting will be organized with the Chemistry DUS. Throughout the academic year, the Chemistry DUS is available (in addition to assigned faculty advisors) to provide students with advice about appropriate courses and future career plans. The Chemistry DUS normally will host at least one lunchtime meeting or similar event each semester for Chemistry Majors to provide feedback about the major and to give input about any changes planned for the major.

Every year the Chemistry Department selects a number of peer mentors. Peer mentors are senior undergraduate students majoring in Chemistry who can provide sage advice to younger students about which courses to complete, how to choose a research group, and good study habits for being successful in chemistry classes. Peer mentors are not able sign student schedules.

For the 2023-2024 academic year, the following individuals serve as peer mentors for Chemistry:

- Nicholas Cerny (nicholas.cerny@yale.edu)
- Madison Houck (madison.houck@yale.edu)
- Deniz Ince (deniz.ince@yale.edu)
- Carmelita Ro-Mendez (carmelita.ro-mendez@yale.edu)

If you are interested in becoming a peer mentor, the DUS typically sends an e-mail to all Chemistry Majors prior to the start of each academic year asking for students to apply (with preference nominally being given to members of the Senior class).

A group of undergraduate students also coordinates the Yale Women in Chemistry Club, which provides a supportive community for women and minorities pursuing the Chemistry Major. Events are held throughout the academic year and are open to all to attend. Information about the Club can be found on Yale Connect (Yale Women in Chemistry).

X. Advising for Students Interested in Health-Care Professions

The Chemistry Major provides students with skills and knowledge that are valuable for a career in health care and, as a consequence, every year a significant number of Chemistry Majors are successfully admitted into medical and related professional schools around the country. Many of the requirements for a B.S. Degree in Chemistry also are necessary for entry into medical school. Premedical students normally complete MB&B 300 (Principles of Biochemistry I) and MB&B 301 (Principles of Biochemistry II), as these classes often are required for entry into medical schools and traditionally are counted as advanced electives towards the Chemistry Major. MCDB 300 (Biochemistry) is an alternative to the MB&B 300/301 sequence, which also is counted as an advanced elective towards the Chemistry Major; however, the Department recommends that Chemistry Majors complete MB&B 300 and MB&B 301, as this provides a more rigorous education in chemical aspects of biochemistry.

The Yale Health Professions Advising Program (HPAP), which is run by the Office of Career Strategy (https://ocs.yale.edu/channels/health-professions/), is a valuable resource for those interested in completing postgraduate education in the medical/health sciences. The Chemistry Department encourages all students interested in such studies to consult with HPAP staff (located on the third floor of 55 Whitney Avenue, phone: (203) 432-0803) as early in their Yale career as possible. The HPAP office will be able to provide the most up-to-date information about the course requirements for different medical schools and general advice on preparing medical school applications. In addition to their academic requirements, premedical students should perform clinical shadowing clinical volunteering and take the MCAT. A general timeline for medical school applications can be found at: https://ocs.yale.edu/channels/medical-school/

Each year the HPAP office, through the Health Professions Advisory Board (HPAB), publishes two bulletins entitled *Preparing to Become a Health Care Professional* and *Applying to Medical School*. The first document contains general information, while the second includes specific details for those about to apply for admission to medical schools (primarily juniors and seniors).

Students who are interested in applying to M.D./Ph.D. programs should consult the online information published by the Association of American Medical Colleges (AAMC) at the following website: https://students-residents.aamc.org/tools-md-phd-applicants/tools-md-phd-applicants

XI. Advising for Students Interested in Ph.D. Programs in Chemistry

Students who are interested in applying to Ph.D. programs in Chemistry should consult with the DUS and their Chemistry Major Faculty Advisor for advice. A B.S. or B.S. (Intensive) degree, as well as research in addition to the requirements for the Chemistry Major, are required for admission into the vast majority of Ph.D., programs in Chemistry. Students who are interested in pursuing a Ph.D. in Chemistry are encouraged to gain research experience starting in their sophomore year and to perform research during at least two summers during their time at Yale. Chemistry Ph.D. Programs sometimes require completion of the Graduate Record Examination (GRE) General and/or Subject Tests. For students who are interesting in attending graduate school immediately after the completion of their Yale Degree, the GRE should be completed in either the fall of their Junior year or in the summer between their Junior and Senior years. Specific information about the requirements for entrance into Chemistry Ph.D. Programs can be found on the Chemistry Department websites of most institutions but applications typically are due in November or December for admission in September of the following year.

XII. Fellowships and Grants

There are many opportunities for students to obtain funding for research and/or study both during their undergraduate years and after their graduation. For example, the Yale Center for International and Professional Experience (CIPE) hosts a website dedicated to the wide variety of possible funding opportunities at https://funding.yale.edu. In particular, this site contains information about fellowships provided by Yale and external scholarships that entail a campus application process. Such programs can provide funding for students over the summer, during the undergraduate academic year, and post-graduation. A searchable directory of this data is available through the Yale Students Grants Database (https://yale.communityforce.com/Funds/Search.aspx). Many of the residential colleges have additional fellowships available to fund summer research and projects during the academic year, all of which can be found on individual residential-college websites. Various databases containing information about external funding opportunities without a campus application process can be found under the "External Awards" heading on the Yale CIPE website at https://funding.yale.edu/fellowships/search-fellowships. Several of the fellowships which Yale Chemistry Majors typically apply for (and in many cases receive) are described below, but for a more comprehensive list, the abovementioned resources should be consulted.

Summer Research for Undergraduates

The *Yale College Dean's Research Fellowship & Rosenfeld Science Scholars Program* provide funding for undergraduate students to perform summer research at Yale. Research must be for a minimum of 10 weeks (which should be consecutive and full-time, with other time commitments, such as employment or coursework, not permitted) and supervised by a member of the Yale faculty. This is the most common way that Chemistry Majors receive funding for summer research. Applications normally are due towards the end of February. More information can be found at the following website: https://science.yalecollege.yale.edu/yale-undergraduate-research/fellowship-grants/yale-college-deans-research-fellowship

The *Science, Technology and Research Scholars* (STARS) *Program* at Yale supports the involvement of women, minority, economically underprivileged, and other historically under-represented students in STEM fields during both academic years and summers. Eligible students may apply for one of three programs. The STARS I Program provides mentoring and professional development for first-year students. The STARS I Summer Research Program includes a $2,500 stipend, as well as room and board, to enable students to spend the summer after their first or sophomore years as laboratory assistants at Yale, with tuition for SCIE 101: *Scientific Research: Process and Presentation* also being covered. In addition to their research, students will participate in a weekly journal club and present their research in a public symposium held at the end of the summer. The STARS II Program provides financial support for students to complete up to 10 hours of laboratory research per week in their junior and senior years, along with a stipend for up to 10 weeks of full-time research in the intervening summer. Participating students present their research at the STARS II Research Symposium held during the spring of their junior and senior years. More information can be found on the STARS website: https://science.yalecollege.yale.edu/stars.

The *National Science Foundation* (NSF) provides support for undergraduate students to become engaged in full-time laboratory research during the summer through the Research Experience for Undergraduates (REU) program, which is held at a variety of universities throughout the country. Students apply for such opportunities through the REU program hosted at a given university, and should check the individual program for specifics about deadlines, stipends, and duration. General information about REUs can be found on the NSF website: https://www.nsf.gov/crssprgm/reu/.

The *National Institutes of Health* (NIH) provides support for undergraduate students to spend a summer performing biomedical research at an NIH facility through their Summer Internship Program (SIP). More information about deadlines, stipends, and duration can be found on the NIH SIP website: https://www.training.nih.gov/programs/sip.

The *National Institute of Standards and Technology* (NIST) provides support for undergraduate students to complete a summer performing full-time research through Summer Undergraduate Research Fellowships (SURFs) in Gaithersburg, MD and Boulder, CO. More information about deadlines, stipends, and duration can be found on the SURF website: https://www.nist.gov/surf.

The *German Academic Exchange Service* (DAAD) provides support for undergraduate students to spend a summer performing full-time research through the Research Internships in Science and Engineering (RISE) program at a variety of institutions throughout Germany. No prior knowledge of German is required. More information about deadlines, stipends, and duration can be found on the DAAD RISE website: https://www.daad.de/rise/en/.

Amgen provides support for undergraduate students to complete a summer performing full-time laboratory research with a biomedical or biotechnology focus at a variety of universities, including Yale. Students apply to the Amgen Scholars Program through an individual university's program and should check the individual program for specifics about deadlines, stipends, and duration. General information about the Amgen Scholars Program can be found on the Amgen Scholar website: https://amgenscholars.com.

Many companies involved in chemical/pharmaceutical research offer summer internships for undergraduate students to gain exposure to and experience in industry. More information can be found on an individual company's website.

Support during the Academic Year

The *Barry M Goldwater Scholarship* provides support for college sophomores and juniors who have a strong commitment to a research career in the natural sciences, mathematics, or engineering. The award provides $7,500 a year to help cover costs associated with tuition, mandatory fees, and books, as well as room and board. The award has an internal campus application process at Yale, so interested student should refer to the Yale CIPE website: https://funding.yale.edu/fellowships.

The *STARS* program at Yale supports the involvement of women, minority, economically under-privileged, and other historically underrepresented students in STEM fields. It provides financial support for students to complete up to 10 hours of laboratory research per week in their junior and senior years. More detailed information about this program can be found on the STARS website: https://science.yalecollege.yale.edu/stars.

Post-Graduation Fellowships

The *NSF* provides grants for students entering or currently enrolled in graduate programs in the sciences for three years of study through the NSF Graduate Research Fellowship Program (NSF GRFP). Students must submit short research proposals, with applications normally being due in early November. Senior Chemistry Majors who are intending to complete a Ph.D. are encouraged to apply. More information can be found on the NSF GRFP website: https://www.nsfgrfp.org.

The *NIH* offers a postbaccalaureate intramural research program, which is designed to provide full-time (lasting 1-3 years), funded biomedical research experiences for students who received their bachelor's degree within the last three years or a master's degree within the last six months and plan to attend graduate or professional school. Further information regarding this program can be found at the following website: https://www.training.nih.gov/programs/postbac_irta.

There a variety of fellowships to support one or more years of graduate study in the United Kingdom, such as the Rhodes, Marshall, Mitchell, and Churchill scholarships. These awards all have internal campus application processes at Yale. For more information about these fellowships, including application processes, durations of awards, and participating institutions, students should refer to the Yale CIPE website: https://funding.yale.edu/fellowships.

Fulbright Grants may be used to support one year of research or graduate study in a variety of countries. These fellowships also have an internal campus application process at Yale, so interested students should refer to the Yale CIPE website: https://funding.yale.edu/fellowships.

XIII. Undergraduate Prizes

The Department awards three prizes to graduating seniors:

(i) The Werner Bergmann Prize: Given to the outstanding senior in the Chemistry Department.

(ii) The Howard Douglass Moore Prize: For excellence in the field of chemistry.

(iii) The Arthur Fleischer Award: For outstanding performance in chemistry.

For each prize, nominations are sought from all faculty members in the Chemistry Department and a faculty committee then selects the winners. Typically, one Bergmann and one Moore Prize are awarded each year, while up to four Fleischer Awards are given. Students receive the Awards at their College Graduation and are not notified prior to this occasion.

XIV. Chemistry Faculty

Research Faculty (*see Section* VIII *above for how to approach faculty about research*)

Amymarie Bartholomew (Inorganic & Materials chemistry) (amymarie.bartholomew@yale.edu)

The goal of research in the Bartholomew group is to use synthetic inorganic chemistry to discover methods to control the properties of physical materials. The materials her group is targeting will respond to changes in temperature, pressure, light, or the presence of small molecules and therefore are expected to serve as sensors or as controllable switches to transform these stimuli into desired outputs.

Victor Batista (Theoretical chemistry) (victor.batista@yale.edu)

The Batista group uses computational approaches to provide fundamental understanding of molecular processes and rigorous interpretations of experiments from first principles. They collaborate with a number of experimental groups in the Chemistry Department.

Gary Brudvig (Biophysical & Inorganic chemistry) (gary.brudvig@yale.edu)

Research in the Brudvig group aims to define how nature has solved the difficult problem of efficient light-driven, four-electron oxidation of water to oxygen and to use this understanding to develop new artificial processes for solar energy conversion.

Jason Crawford (Chemical biology) (jason.crawford@yale.edu)

The Crawford laboratory is developing and systematically applying genome sequence-guided methods for the discovery of genetically encoded small molecules from mutualistic and pathogenic microorganisms.

Craig Crews† (Chemical biology) (craig.crews@yale.edu)

Through natural product total synthesis, affinity reagent generation, and biochemical methodologies, the Crews lab identifies natural product target proteins, which serve as the starting point for the rapid development of compounds for the treatment of diseases.

Caitlin Davis (Biophysical chemistry) (c.davis@yale.edu)

The Davis laboratory uses experiments at multiple scales, from *in vitro* to single cell to whole organism, to study fundamental and applied problems at the intersection of chemistry, physics, and biology. A common theme of their research is the development of quantitative spectroscopic imaging techniques to investigate the relationship between function and dynamics in biological systems.

Jonathan Ellman (Organic chemistry & Chemical biology) (jonathan.ellman@yale.edu)

The Ellman group's research emphasizes the development of practical and general synthetic methods and their application to the preparation of pharmaceutical agents and bioactive natural products. His laboratory is also actively engaged in the development and application of chemical tools to study different classes of enzymes.

Sharon Hammes-Schiffer (Theoretical chemistry) (sharon.hammes-schiffer@yale.edu)

Research in the Hammes-Schiffer group focusses on the development and application of theoretical and computational methods for describing chemical reactions in condensed phases and at interfaces. Their overall objectives are to elucidate the fundamental physical principles underlying charge transfer processes and catalysis, as well as to assist in the interpretation of experimental data.

Stavroula Hatzios[†] (Chemical biology) (stavroula.hatzios@yale.edu)

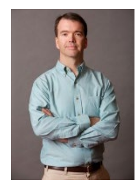
The Hatzios laboratory uses chemical and biological tools to identify proteins that are active during gastrointestinal infections, determine how they respond to environmental cues, and characterize their molecular contributions to disease.

Nilay Hazari (Inorganic chemistry) (nilay.hazari@yale.edu)

The Hazari group works in the area of organometallic chemistry. Their goal is rationally design new catalysts for a range of processes based on detailed studies of reaction mechanisms.

Seth Herzon (Organic chemistry & Chemical biology) (seth.herzon@yale.edu)

Research in the Herzon group centers on natural products chemistry with an emphasis on the synthesis and study of DNA-damaging natural products, human microbiota metabolites, and antibiotics. They also have projects in synthetic methods typically motivated by challenges encountered in synthesis.

Patrick Holland (Inorganic chemistry) (patrick.holland@yale.edu)

The Holland group focuses on the synthesis and reactions of inorganic complexes that break bonds in small molecules such as N_2, H_2, and CO_2. They use a range of spectroscopic, crystallographic, and mechanistic techniques.

Mark Johnson (Physical chemistry) (mark.johnson@yale.edu)

The Johnson laboratory specializes in identifying the factors that control macroscopic behavior at the molecular level. They accomplish this by *designing and building* new types of hybrid instrumentation that integrate laser spectroscopy with cryogenic mass spectrometry.

William Jorgensen (Organic chemistry) (william.jorgensen@yale.edu)

The Jorgensen laboratory specializes in organic, computational, and biochemistry applied to drug discovery, including computer-aided design, organic synthesis, biological assaying, and protein crystallography.

Patrick Loria (Biophysical chemistry) (patrick.loria@yale.edu)

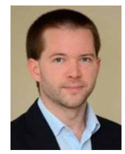
Research in the Loria group aims to understand how the dynamic and structural properties of proteins correlate with their function with emphasis on enzymes and allosterism. Their primary experimental tool for add ressing these questions is nuclear magnetic resonance spectroscopy, which allows quantitative, atomic-resolution insight into the kinetics, thermodynamics, and mechanism these important enzyme motions.

Stacy Malaker (Chemical biology) (stacy.malaker@yale.edu)
The goal of research in the Malaker group is to develop methods that allow for mass spectrometry (MS) analysis of mucin-domain glycoproteins, a class of densely O-glycosylated extracellular proteins. They also study mucins in a biological context, since these proteins are integral in diseases including: cancer, cystic fibrosis, and inflammatory bowel disease.

James Mayer (Inorganic & Materials chemistry) (james.mayer@yale.edu)
The Mayer laboratory studies the fundamental chemical reactions of molecules and materials, including synthesis, spectroscopy, kinetics and electrochemistry.

Scott Miller (Organic chemistry) (scott.miller@yale.edu)
The Miller laboratory is interested in all aspects of chemical and biological catalysis, including reaction mechanisms and application in organic synthesis.

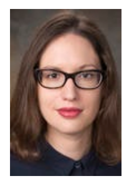
Tim Newhouse (Organic chemistry) (timothy.newhouse@yale.edu)
The Newhouse group synthesizes complex natural products and develops new synthetic methods to prepare these complex small molecules. The properties of newly prepared natural products are exploited for a variety of purposes by collaborating with neuroscientists.



Anna Pyle[†] (Chemical biology) (anna.pyle@yale.edu)
The Pyle group studies RNA structure and RNA recognition by protein enzymes. They use a combination of experimental biochemistry, crystallography, and computation to study the architectural features of large RNA molecules, such as self-splicing introns and other noncoding RNAs

James Rothman[†] (Cell biology) (james.rothman@yale.edu)
The Rothman laboratory is interested in elucidating the underlying mechanisms of vesicular transport within cells and the secretion of proteins. They take an interdisciplinary approach which includes cell-free biochemistry, single-molecule biophysics, high-resolution optical imaging of single events/single molecules in the cell and in cell-free formats.

Sarah Slavoff (Chemical biology) (sarah.slavoff@yale.edu)
The Slavoff group is interested in developing new tools to elucidate novel functions of RNA in cells, including non-canonical translation and RNA degradation in cytoplasmic granules. They utilize a broad range of interdisciplinary methods, including mass-spectrometry-based proteomics, microscopy, structural biology, and small molecule-mediated control of biomolecular function.



David Spiegel (Chemical biology) (david.spiegel@yale.edu)
The Spiegel laboratory develops novel chemical methods to enable the synthesis of a variety of complex molecular targets, including natural products. These synthetic materials are used to study the molecular mechanisms that underlie human disease processes (e.g., cancer, Alzheimer's disease, and diabetes) as well as to develop novel therapeutic approaches to these conditions.

Scott Strobel[†] (Chemical biology) (scott.strobel@yale.edu)
Research in the Strobel laboratory is divided between work on RNA biochemistry and the investigation of novel endophytic fungi associated with rainforest plants. The goal is to understand how RNA promotes chemical reactions and to define the basis of RNA-small molecule interactions.

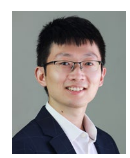
Patrick Vaccaro (Physical chemistry) (patrick.vaccaro@yale.edu)
Research in the Vaccaro group strives to elucidate the origins of molecular behavior by probing fundamental physical properties and chemical propensities through synergistic application of modern laser-spectroscopic and quantum-chemical tools. Information gleaned from such studies affords a trenchant glimpse of structural paradigms and dynamical processes that permeate the entire fabric of chemistry, including molecular chirality, non-covalent interactions, and proton-transfer reactions.

Hailiang Wang (Materials chemistry) (hailiang.wang@yale.edu)
The Wang group focuses on materials and surface chemistry for electrochemical energy storage and conversion.

Elsa Yan (Biophysical & physical chemistry) (elsa.yan@yale.edu)
The Yan group focusses on protein folding at membrane surfaces and signal transduction across biomembranes through G protein-coupled receptors (GPCRs). They apply second-order laser spectroscopy and biophysical methods to obtain thermodynamic and kinetic information to investigate structure and functions of the proteins.

Mingjiang Zhong[†] (Materials chemistry) (mingjiang.zhong@yale.edu)
Research in the Zhong group explores new synthetic methods for the preparation of functional organic materials and organic-inorganic interfaces and polymeric and polymer-derived carbon materials for energy, catalysis, and environmental applications.

Tianyu Zhu (Theoretical chemistry) (tianyu.zhu@yale.edu)
The Zhu group develops high-accuracy computational methods for understanding how electronic interactions and movements govern chemical reactions and material properties. They utilize techniques from quantum chemistry, materials modeling, and machine learning to address challenges in computational design of catalysts, quantum materials, and solar cells.



Kurt Zilm (Physical chemistry) (kurt.zilm@yale.edu)
Research in the Zilm laboratory involves development of new NMR methods and their application to important problems in chemistry and materials science. Recent interests include the use of site specific solid state NMR relaxation measurements to characterize protein backbone motions and to measure difficult to access long range distance constraints.

[†] These faculty members have primary appointments in Departments other than Chemistry. It is still possible for undergraduate students to perform research as part of CHEM 480 or CHEM 490 in these groups, but the DUS should be consulted prior to the commencement of research.

Teaching Faculty‡

Paul Cooper (paul.d.cooper@yale.edu)
Dr. Cooper has a background in physical chemistry. He typically teaches General Chemistry and Physical Chemistry Laboratory.

Christine DiMeglio (christine.dimeglio@yale.edu)
Dr. DiMeglio has a background in organic chemistry. She typically teaches Organic Chemistry Laboratory and the Advanced Laboratory.

Laura Herder (laura.herder@yale.edu)
Dr. Herder has a background in materials and physical chemistry. She typically teaches courses associated with the General Chemistry sequence and chemistry courses for non-majors.

Jonathan Parr (jonathan.parr@yale.edu)
Dr. Parr has a background in inorganic chemistry. He typically teaches General Chemistry, Inorganic Laboratory, and the Advanced Laboratory, and is normally in charge of CHEM 400 and CHEM 490.

‡ Students do not normally perform independent research with teaching faculty.

XV. Chemistry Forms

Course of Study Forms:

- **Bachelor of Arts, Bachelor of Science, and Bachelor of Science (Intensive Major degrees**

- **Combined Bachelor of Science/Master of Science degree**

Undergraduate Research Forms:

- **CHEM 480 Registration Form (Introduction to Independent Research in Chemistry)**
- **CHEM 490 Registration Form (Independent Research in Chemistry)**
- **Undergraduate Research Registration Form**

Other Yale College Forms & Petitions | University Registrar's Office (yale.edu)