CHEMICAL ENGINEERING


Research investigations are currently being carried out in the following fields: applied statistical mechanics, biocalcification, bioengineering, biophysics, colloid science, computational materials science, electronic materials, hydrodynamic stability, kinetics and catalysis, Newtonian and non-Newtonian fluid mechanics, polymer science, renewable energy, rheo-optics of polymeric systems, and surface and interface science. Additional information may be found at [http://cheme.stanford.edu](http://cheme.stanford.edu).

The Department of Chemical Engineering offers opportunities for both undergraduates and graduate students to pursue course work and research in energy sciences and technology, which include the chemical, physical, mathematical, and engineering sciences.

In addition, both undergraduates and graduate students can pursue work in interdisciplinary biosciences, which include the chemical, biological, physical, mathematical, and engineering sciences. Students are encouraged to review course offerings in all departments of the School of Engineering and to seek academic advising with individual chemical engineering faculty. Students wishing assistance should talk with student services staff in the department.

Further information about the department also may be found on the department's website [http://cheme.stanford.edu](http://cheme.stanford.edu). Undergraduates considering majoring in Chemical Engineering are encouraged to talk with faculty and to meet with student services' staff in Shriram room 129. Students interested in pursuing advanced work in chemical engineering, including coterminal degrees, should contact the student services manager. Admission to an advanced degree program for an active Stanford graduate student is by approval of a Graduate Authorization Petition. All other interested applicants should go to the Graduate Admissions [https://gradadmissions.stanford.edu](https://gradadmissions.stanford.edu) website for general and departmental information about the requirements and processes for applying for admission to a graduate degree program.

Mission of the Undergraduate Program in Chemical Engineering

Chemical engineers are responsible for the conception and design of processes for the purpose of production, transformation, and transportation of materials. This activity begins with experimentation in the laboratory and is followed by implementation of the technology in full-scale production. The mission of the undergraduate program in Chemical Engineering is to develop students' understanding of the core scientific, mathematical, and engineering principles that serve as the foundation underlying these technological processes. The program's core mission is reflected in its curriculum which is built on a foundation in the sciences of chemistry, physics, and biology. Course work includes the study of applied mathematics, material and energy balances, thermodynamics, fluid mechanics, energy and mass transfer, separations technologies, chemical reaction kinetics and reactor design, and process design. The program provides students with excellent preparation for careers in the corporate sector and government or for advanced study.

Learning Outcomes (Undergraduate)

Learning outcomes are used in evaluating students and the undergraduate program. The department expects undergraduate majors in the program to be able to demonstrate the following:

1. an ability to apply knowledge of mathematics, science, and engineering.
2. an ability to design and conduct experiments, as well as to analyze and interpret data.
3. an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
4. an ability to function on multidisciplinary teams.
5. an ability to identify, formulate, and solve engineering problems.
6. an understanding of professional and ethical responsibility.
7. an ability to communicate effectively.
8. the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.
9. a recognition of the need for, and an ability to engage in life-long learning.
10. a knowledge of contemporary issues.
11. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Learning Outcomes (Graduate)

The purpose of the master's program is to provide students with the knowledge and skills necessary for a professional career or doctoral studies. This is done through advanced lecture course work in the fundamentals of the field, including microhydrodynamics, molecular thermodynamics, kinetics, spectroscopy, applied mathematics, and biochemical engineering, in addition to the student's area of specialization. All students must master the fundamental chemical, physical, and biological concepts that govern molecular behavior.

The Ph.D. is conferred upon candidates who have demonstrated substantial scholarship and the ability to conduct independent research. Through course work and guided research, the program prepares students to make original contributions in Chemical Engineering and related fields.

Graduate Programs in Chemical Engineering

The University's requirements, including residency requirements, for the M.S., Engineer, and Ph.D. degrees are summarized in the "Graduate Degrees [http://exploredegrees.stanford.edu/graduatedegrees)](https://exploredegrees.stanford.edu/graduatedegrees)" section of this bulletin.

Current research and teaching activities cover a number of advanced topics in chemical engineering, including applied statistical mechanics, biocalcification, biochemical engineering, bioengineering, biophysics, computational materials science, colloid science, dynamics of complex fluids, energy conversion, functional genomics, hydrodynamic stability, kinetics and catalysis, micro rheology, molecular assemblies, nanoscience and technology, Newtonian and non-Newtonian fluid mechanics, polymer physics, protein biotechnology, renewable fuels, semiconductor processing, soft materials science, solar utilization, surface and interface science, and transport mechanics.

Fellowships and Assistantships

Qualified predoctoral applicants are encouraged to apply for nationally competitive fellowships, for example, those from the National Science Foundation. Applicants to the Ph.D. program should consult with
their financial aid officers for application information and advice. In the absence of other awards, incoming Ph.D. students normally are awarded departmental fellowships. Matriculated Ph.D. students are supported primarily by fellowship awards and assistantship research or teaching appointments. All students are encouraged to apply for external competitive fellowships and may obtain information about various awarding agencies from faculty advisers and student services. Assistantships are paid positions for graduate students that, in addition to a salary, provide the benefit of a tuition allocation. Individual faculty members appoint students to research assistantships; the department chair appoints doctoral students to teaching assistantships. Contact departmental student services for additional information.

Bachelor of Science in Chemical Engineering

The Chemical Engineering B.S. program requires basic courses in biology, chemistry, engineering, mathematics, and physics. The depth sequence of courses required for the major in chemical engineering provides training in applied chemical kinetics, biochemical engineering, electronic materials, engineering thermodynamics, plant design, polymers, process analysis and control, separation processes, and transport phenomena. Undergraduates who are considering and/or wish to major in chemical engineering should talk with departmental student services as early as during freshman orientation if feasible and consult the curriculum outlined in the "Undergraduate Program in Chemical Engineering" section of this bulletin. Courses taken to fulfill the requirements for the major (courses in mathematics; science; technology and society; engineering fundamentals; and engineering depth) must be taken for a letter grade if this option is offered.

Representative sequences of courses leading to a B.S. in Chemical Engineering, in both flow chart and 4-year, quarter-by-quarter formats, can be found in the Handbook for Undergraduate Engineering Programs, available at http://ughb.stanford.edu. These are explanatory examples, with each sequence starting at a different level and demonstrating how a student, based on his or her pre-college preparation, can complete the major in four years. These typical course schedules are available as well from departmental student services and chemical engineering faculty advisers for undergraduates. It is recommended that students discuss their prospective programs with the chemical engineering faculty advisers, particularly if they are transferring from another major such as Biology, Chemistry, Physics, or another Engineering major. With advance planning, students can usually arrange to attend one of the overseas campuses.

Students interested in a minor in Chemical Engineering should consult the requirements for a "Minor in Chemical Engineering (p. 3)" section of this bulletin.

Chemical Engineering

Completion of the undergraduate program in Chemical Engineering leads to the conferment of the Bachelor of Science in Chemical Engineering.

Mission of the Undergraduate Program in Chemical Engineering

Chemical engineers are responsible for the conception and design of processes for the purpose of production, transformation, and transportation of materials. This activity begins with experimentation in the laboratory and is followed by implementation of the technology in full-scale production. The mission of the undergraduate program in Chemical Engineering is to develop students’ understanding of the core scientific, mathematical, and engineering principles that serve as the foundation underlying these technological processes. The program’s core mission is reflected in its curriculum which is built on a foundation in the sciences of chemistry, physics, and biology. Course work includes the study of applied mathematics, material and energy balances, thermodynamics, fluid mechanics, energy and mass transfer, separations technologies, chemical reaction kinetics and reactor design, and process design. The program provides students with excellent preparation for careers in the corporate sector and government, or for graduate study.

Requirements

### Mathematics

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 19 Calculus</td>
<td>5</td>
</tr>
<tr>
<td>MATH 20 Calculus</td>
<td>5</td>
</tr>
<tr>
<td>MATH 21 Calculus</td>
<td>5</td>
</tr>
</tbody>
</table>

Select one of the following: 5-10 units

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEMENG 102 Ordinary Differential Equations for Engineers or MATH 53 Ordinary Differential Equations with Linear Algebra</td>
<td>5</td>
</tr>
</tbody>
</table>

Select one of the following: 4-5 units

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEMENG 104 Linear Algebra and Partial Differential Equations for Engineers or CHEMENG 106 Introduction to Probability and Statistics for Engineers</td>
<td>4-5</td>
</tr>
</tbody>
</table>

### Science

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEM 31M Chemical Principles: From Molecules to Solids</td>
<td>5</td>
</tr>
<tr>
<td>CHEM 33 Structure and Reactivity of Organic Molecules</td>
<td>5</td>
</tr>
<tr>
<td>CHEM 121 Organic Chemistry of Bioactive Molecules</td>
<td>5</td>
</tr>
<tr>
<td>CHEM 123 Organic Polynuclear Compounds</td>
<td>3</td>
</tr>
<tr>
<td>PHYSICS 41 Mechanics</td>
<td>4</td>
</tr>
<tr>
<td>or PHYSICS 41E Mechanics, Concepts, Calculations, and Context</td>
<td>4</td>
</tr>
<tr>
<td>PHYSICS 43 Electricity and Magnetism</td>
<td>4</td>
</tr>
</tbody>
</table>

### Technology in Society

One course required, see Basic Requirement 4; course chosen must be on the SoE-Approved Courses list at <ughb.stanford.edu> the year taken.

### Engineering Fundamentals

Two courses minimum; see Basic Requirement 3

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEMENG/ENGR 20 Introduction to Chemical Engineering</td>
<td>4</td>
</tr>
<tr>
<td>Fundamentals Elective from another School of Engineering department</td>
<td>3-5</td>
</tr>
</tbody>
</table>

### See the UGHB for a list of courses.

### Chemical Engineering Depth

| Minimum 68 Engineering Science and Design units; see Basic Requirement 5 |
|-----------------------------|-------------------------|
| CHEMENG 10 The Chemical Engineering Profession | 1     |
| CHEMENG 100 Chemical Process Modeling, Dynamics, and Control | 3     |
| CHEMENG 110A Introduction to Chemical Engineering Thermodynamics | 3     |
| CHEMENG 110B Multi-Component and Multi-Phase Thermodynamics | 3     |
| CHEMENG 120A Fluid Mechanics | 4     |
| CHEMENG 120B Energy and Mass Transport | 4     |
| CHEMENG 130A Microkinetics - Molecular Principles of Chemical Kinetics | 3     |
| CHEMENG 150 Biochemical Engineering | 3     |
CHEMENG 170 Kinetics and Reactor Design 3
CHEMENG 180 Chemical Engineering Plant Design 4
CHEMENG 181 Biochemistry I 4
CHEMENG 185A Chemical Engineering Laboratory A (WIM) 4
CHEMENG 185B Chemical Engineering Laboratory B 4

Select four of the following 1,2,3

CHEMENG 140 Micro and Nanoscale Fabrication Engineering
CHEMENG 142 Basic Principles of Heterogeneous Catalysis with Applications in Energy Transformations
CHEMENG 160 Polymer Science and Engineering
CHEMENG 174 Environmental Microbiology I
CHEMENG 177 Data Science and Machine Learning Approaches in Chemical and Materials Engineering
CHEMENG 183 Biochemistry II
CHEMENG 196 Creating and Leading New Ventures in Engineering and Science-based Industries

Total Units 115-125

1. Unit count is higher if program includes one or more of the following: MATH 51 and MATH 52 in lieu of CME 100; or CHEM 31A and CHEM 31B in lieu of CHEM 31M.
2. Students may substitute two of the depth electives with 100-level lecture or lab course(s) offered in one of the following engineering disciplines: BIOE, CEE, CME, CS, EE, MS&E, MATSCI, and ME (must be taken for a minimum of 3 units total). One or two 100-level lecture or lab course(s) offered in chemistry, math, biology, or physics. Students may also use courses with the prefix ENERGY (with dept approval). Courses at the 200, 300, and 400 level may be used as long as the department receives documentation from the instructor that shows the student has been received their permission to enroll in the course. See Handbook for Undergraduate Engineering Programs (UGHB) (http://ughb.stanford.edu) for additional details.
3. A course may only be counted towards one requirement; it may not be double-counted. All courses taken for the major must be taken for a letter grade if that option is offered by the instructor. Minimum Combined GPA for all courses in Engineering Fundamentals and Depth is 2.0.
4. Students who completed CHEM 171 prior to academic year 2019-20 may substitute CHEMENG 110A with CHEM 171.
5. Students who completed CHEMENG 110 prior to academic year 2019-20 may substitute CHEMENG 110B with CHEMENG 110.
6. Students who completed CHEMENG 130 prior to academic year 2019-20 may substitute CHEMENG 130A with CHEMENG 130.

For additional information and sample programs, see the Handbook for Undergraduate Engineering Programs (UGHB) (http://ughb.stanford.edu)

Honors Program in Chemical Engineering

The Department of Chemical Engineering offers a program leading to the degree of Bachelor of Science in Chemical Engineering with Honors. Qualified undergraduate majors conduct independent study and research at an advanced level with faculty mentors, graduate students, and fellow undergraduates. This three quarter sequential program requires concurrent participation each quarter in the CHEMENG 191H Undergraduate Honors Seminar; completion of a faculty-approved thesis, and participation in the Chemical Engineering Honors Poster Session held annually during the Mason Lecture Series Spring Quarter. The last requirement may be fulfilled through an alternative, public, oral presentation with the approval of the department chair. A research proposal/application must be submitted at least five quarters prior to graduation with work to begin at a minimum of four quarters prior to graduation.

Admission to the honors program is by application and submission of a research proposal and is subject to approvals by faculty advisers, sponsors, and the chair of the department. Declared Chemical Engineering majors with a cumulative grade point average (GPA) of 3.5 or higher are encouraged to apply. Students must submit their applications no later than the first week in March during Winter Quarter of their junior year, assuming a June degree conferral the following year, e.g. the 2019-2020 deadline is March 2, 2020. An application includes a Stanford transcript in addition to the research proposal, approved by both the student’s research thesis adviser, a faculty reader, and, if required, a chemical engineering faculty sponsor. The research adviser or the reader or, alternatively, a faculty sponsor, must be a faculty member in the Department of Chemical Engineering. Students must start their research no later than Spring Quarter their junior year and are encouraged to consider incorporating research opportunities such as those sponsored by Undergraduate Academic Life into their honors research proposal; see http://ual.stanford.edu/OO/research_opps/Grants. See departmental student services staff in Shriram Center room 129, for more information about the application process, a proposal template, and other assistance.

In order to receive departmental honors, students admitted to the honors program must:

1. Maintain an overall grade point average (GPA) of at least 3.5 as calculated on the unofficial transcript.
2. Complete at least three quarters of research with an aggregate enrollment of a minimum of nine units in CHEMENG 190H Undergraduate Honors Research in Chemical Engineering for a letter grade; up to three units may be used towards the Chemical Engineering depth elective requirements. All quarters must focus on the same topic. The same faculty adviser and faculty reader should be maintained throughout if feasible.
3. Enroll in CHEMENG 191H Undergraduate Honors Seminar, concurrently with each quarter of enrollment in CHEMENG 190H Undergraduate Honors Research in Chemical Engineering.
4. Participate with a poster and oral presentation of thesis work at the Chemical Engineering Honors Poster Session held during the Mason Lectures week, Spring Quarter, or, at the Undergraduate Program Committee’s discretion, at a comparable public event. Submit at the same time to student services one copy of the poster in electronic format.
5. Submit final drafts of a thesis simultaneously to the adviser and the reader and, if appropriate, to the Chemical Engineering faculty sponsor, no later than April 6, 2020, or the first school day of the second week of the quarter in which the degree is to be conferred.
6. Complete all work and thesis revisions and obtain indicated faculty approvals on the Certificate of Final Reading of Thesis forms by April 30, 2020, or the end of the first month of the graduation quarter.
7. Submit to departmental student services one (1) final copy of the honors thesis, as approved by the appropriate faculty. Include in each thesis an original, completed, faculty signature sheet immediately following the title page. The 2019-2020 deadline is May 4, 2020.
8. Submit to student services a copy of the honors thesis in electronic format at the same time as the final copy of the thesis.

Upon faculty approval, departmental student services to submit one electronic copy of each honors thesis to Student Affairs, School of Engineering.

Chemical Engineering Minor

The following core courses fulfill the minor requirements:
Chemical Engineering

Master of Science in Chemical Engineering

A range of M.S. programs comprising appropriate course work is available to accommodate students wishing to obtain further academic preparation before pursuing a chemical engineering career or a degree program. The degree requirements are lecture course based; there are no research or thesis requirements. This is a terminal M.S. degree, i.e., the degree is not a prerequisite for nor does it lead to admission to the department’s Ph.D. program.

Coterminal master’s students should see the specific requirements for the coterminal degree below.

For conferral of a master’s degree in Chemical Engineering, the following departmental requirements must be met.

Unit and Course Requirements for the Master's Degree

Students terminating their graduate work with the M.S. degree in Chemical Engineering must develop a graduate-level, thematic M.S. program consisting of a minimum of 45 completed units of academic work that includes:

1. Four (4) Chemical Engineering core graduate lecture courses selected from the CHEMENG 300 series listed below.

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEMENG 300</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 310</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 320</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 340</td>
<td>3</td>
</tr>
</tbody>
</table>

May select from:

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEMENG 345</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 355</td>
<td>3</td>
</tr>
</tbody>
</table>

2. An additional four (4) Chemical Engineering graduate-level lecture courses. May not use CHEMENG 699 Colloquium or any CHEMENG 500-level course.

3. Three (3) units of CHEMENG 699 Colloquium.

4. An additional 18 units, selected from graduate-level science, math, or engineering lecture courses (3 units or more) in any appropriate department. Of these 18 units, 6 must be graduate-level science, math, or engineering lecture courses. The remaining 12 units can come from a combination of the following categories:

   - An additional 3-12 units of graduate-level science, math, or engineering lecture courses.
   - No more than 6 units of non-science, math, or engineering lecture courses.
   - No more than 6 units of lab courses.
   - No more than 6 units combined of research units or seminar courses on science, math, or engineering topics under the following conditions:
     - Up to 6 units of research.
     - No more than 3 of these 6 units can be taken as seminar courses; examples include: 1 unit seminar and 5 units research; 2 units seminar and 4 units research; 3 units seminar and 3 units research.

Credit toward the required minimum of 45 completed units for the M.S. degree is not given for Chemical Engineering special topics courses numbered in the 500 series.

To ensure that an appropriate Chemical Engineering graduate program is pursued by each M.S. candidate, students who first matriculate at Stanford at the graduate level must do the following, during the first quarter, no later than the seventh week:

1. Complete a Program Proposal for a Master's Degree form, that is approved by the M.S. adviser.
2. Submit this petition form to departmental student services, for review by the graduate curriculum committee.
3. Obtain approval for any subsequent program change or changes, using a freshly completed Program Proposal form, from the M.S. adviser and the faculty chair of the graduate curriculum committee.

All M.S. candidates must obtain approvals for the final M.S. program no later than the seventh week of the quarter preceding the quarter of degree conferral, in order to permit amendment of the final quarter's study list if the faculty deem this necessary. Students with questions should contact departmental graduate student services.

Minimum Grade Requirement

Any course used to satisfy the 45-unit minimum for the Master of Science degree must be taken for a letter grade, if offered. An overall grade point average (GPA) of 3.0 must be maintained for these courses.

Research Experience

Students in the M.S. program wishing to obtain research experience should talk with departmental student services and work with the M.S. faculty adviser on the choice of research adviser as early as feasible and in advance of the anticipated quarter(s) of research. Once arrangements are mutually agreed upon, including the number of units, students enroll in the appropriate section of CHEMENG 600 Graduate Research in Chemical Engineering. A written report describing the results of the research undertaken must be submitted to and approved by the research adviser. Research units may not be substituted for any of the required four 300-level core lecture courses.

1 Students who completed CHEM 171 prior to academic year 2019-20 may substitute CHEMENG 110A with CHEMENG 110.

2 Students who completed CHEMENG 110 prior to academic year 2019-20 may substitute CHEMENG 110B with CHEMENG 110.
Coterminal Master's Degrees in Chemical Engineering

Stanford undergraduates with strong academic records may apply to study for a master's degree while at the same time completing their bachelor's degree(s). Interested students should discuss their educational goals with their faculty advisers and talk with departmental graduate student services about the application requirements before submitting an application in Axess. Students, who have completed at least 120 units toward an undergraduate degree and complete their applications by the seventh week of a quarter, may be admitted to the Chemical Engineering M.S. program the following quarter. The GRE is not required for students applying for the Chemical Engineering coterminal master's degree.

University Coterminal Requirements

Coterminal master's degree candidates are expected to complete all master's degree requirements as described in this bulletin. University requirements for the coterminal master's degree are described in the “Coterminal Master's Program (http://exploredegrees.stanford.edu/cotermdegrees)” section. University requirements for the master's degree are described in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees/#masterstext)” section of this bulletin.

After accepting admission to this coterminal master's degree program, students may request transfer of courses from the undergraduate to the graduate career to satisfy requirements for the master's degree. Transfer of courses to the graduate career requires review and approval of both the undergraduate and graduate programs on a case by case basis.

In this master's program, courses taken during or after the first quarter of the sophomore year are eligible for consideration for transfer to the graduate career; the timing of the first graduate quarter is not a factor. No courses taken prior to the first quarter of the sophomore year may be used to meet master's degree requirements.

Course transfers are not possible after the bachelor's degree has been conferred.

The University requires that the graduate adviser be assigned in the student's first graduate quarter even though the undergraduate career may still be open. The University also requires that the Master's Degree Program Proposal be completed by the student and approved by the department by the end of the student's first graduate quarter.

Master of Science in Chemical Engineering

A range of M.S. programs comprising appropriate course work is available to accommodate students wishing to obtain further academic preparation before pursuing a chemical engineering career or a degree program. The degree requirements are lecture course based; there are no research or thesis requirements. This is a terminal M.S. degree, i.e. this degree is not a prerequisite for nor does it lead to admission to the department's Ph.D. program.

The Honors Cooperative Program (HCP) M.S. program, available completely online, makes it possible for academically qualified engineers and scientists in industry to be part-time graduate students in Chemical Engineering while continuing professional employment. Prospective HCP M.S. students follow the same admissions process and must meet the same admissions requirements as full-time residential M.S. students.

For conferral of a master’s degree in Chemical Engineering, the following departmental requirements must be met.

Unit and Course Requirements for the Master’s Degree

Students terminating their graduate work with the M.S. degree in Chemical Engineering must develop a graduate-level, thematic M.S. program consisting of a minimum of 45 completed units of academic work that includes:

1. Four (4) Chemical Engineering core graduate lecture courses selected from the CHEMENG 300 series listed below.

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<th>Units</th>
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</thead>
<tbody>
<tr>
<td>CHEMENG 300</td>
<td>Applied Mathematics in the Chemical and Biological Sciences</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 310</td>
<td>Microhydrodynamics</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 320</td>
<td>Chemical Kinetics and Reaction Engineering</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 340</td>
<td>Molecular Thermodynamics</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 345</td>
<td>Fundamentals and Applications of Spectroscopy</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 355</td>
<td>Advanced Biochemical Engineering</td>
<td>3</td>
</tr>
</tbody>
</table>

2. An additional four (4) Chemical Engineering graduate-level lecture courses. May not use CHEMENG 699 Colloquium or any CHEMENG 500-level course.
   - Additional core Chemical Engineering lecture course from the CHEMENG 300 series.
   - Graduate electives in Chemical Engineering.

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEMENG 242</td>
<td>Basic Principles of Heterogeneous Catalysis with Applications in Energy Transformations</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 283</td>
<td>Biochemistry II</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 296</td>
<td>Creating and Leading New Ventures in Engineering and Science-based Industries</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 432</td>
<td>Electrochemical Energy Conversion</td>
<td>3</td>
</tr>
</tbody>
</table>

3. HCP students may use any of the following to satisfy this requirement:
   - Three (3) units of a seminar/speaker series in engineering, science, or math.
   - A three-unit graduate course in engineering, science, or math.

4. An additional 18 units, selected from graduate-level science, math, or engineering lecture courses (3 units or more) in any appropriate department. Of these 18 units, 6 must be graduate-level science, math, or engineering lecture courses. The remaining 12 units can come from a combination of the following categories:
   - An additional 3-12 units of graduate-level science, math, or engineering lecture courses.
   - No more than 6 units of non-science, math, or engineering lecture courses.
   - No more than 3 units of seminar courses on science, math, or engineering topics.

Credit toward the required minimum of 45 completed units for the M.S. degree is not given for Chemical Engineering special topics courses numbered in the 500 series.

To ensure that an appropriate Chemical Engineering graduate program is pursued by each M.S. candidate, students who first matriculate at Stanford at the graduate level must do the following, during the first quarter, no later than the seventh week:

1. Complete a Program Proposal for a Master's Degree form, that is approved by the M.S. adviser.
2. Submit this petition form to departmental student services, for review by the graduate curriculum committee.

3. Obtain approval for any subsequent program change or changes, using a freshly completed Program Proposal form, from the M.S. adviser and the faculty chair of the graduate curriculum committee.

All M.S. candidates must obtain approvals for the final M.S. program no later than the seventh week of the quarter preceding the quarter of degree conferral, in order to permit amendment of the final quarter's study list if the faculty deem this necessary. Students with questions should contact departmental graduate student services.

**Minimum Grade Requirement**

Any course used to satisfy the 45-unit minimum for the Master of Science degree must be taken for a letter grade, if offered. An overall grade point average (GPA) of 3.0 must be maintained for these courses.

**Research Experience**

Students in the M.S. program wishing to obtain research experience should talk with departmental student services and work with the M.S. faculty adviser on the choice of research adviser as early as feasible and in advance of the anticipated quarter(s) of research. Once arrangements are mutually agreed upon, including the number of units, students enroll in the appropriate section of CHEMENG 699 Graduate Research in Chemical Engineering. A written report describing the results of the research undertaken must be submitted to and approved by the research adviser. Research units may not be substituted for any of the required four 300-level core lecture courses.

**Engineer in Chemical Engineering**

The degree of Engineer is awarded after the completion of a minimum of 90 units of graduate work beyond the B.S. degree and the satisfactory completion of all University requirements plus the following departmental requirements. Application to this program is open only to active chemical engineering M.S. or Ph.D. candidates. This degree is not a prerequisite for the Ph.D. program.

**Unit and Course Requirements**

A minimum of 90 completed units is required, including a component of a minimum of 45 units in science and engineering courses, consisting of 42 lecture units and 3 CHEMENG 699 Colloquium units. The required CHEMENG courses are listed below.

<table>
<thead>
<tr>
<th>Course</th>
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</tr>
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<tbody>
<tr>
<td>CHEMENG 300</td>
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<td>CHEMENG 310</td>
<td>Microhydrodynamics</td>
</tr>
<tr>
<td>CHEMENG 320</td>
<td>Chemical Kinetics and Reaction Engineering</td>
</tr>
<tr>
<td>CHEMENG 340</td>
<td>Molecular Thermodynamics</td>
</tr>
<tr>
<td>CHEMENG 345</td>
<td>Fundamentals and Applications of Spectroscopy</td>
</tr>
<tr>
<td>CHEMENG 355</td>
<td>Advanced Biochemical Engineering</td>
</tr>
<tr>
<td>Plus 3 units of: CHEMENG 699 Colloquium</td>
<td>1</td>
</tr>
</tbody>
</table>

The additional lecture courses, (24 units), may be chosen from graduate level science and engineering courses according to the guidelines given in the "Master's (p. 4)" section and with the consent of the graduate curriculum committee chair and the department chair. In fulfilling the required 45-unit requirement for lecture course units, the course work may not include chemical engineering's 500 level seminar courses or similar 1-2 unit courses in other departments. The remaining 45 units are primarily research units.

Students seeking the Engineer degree may petition to add a M.S. program and apply for the M.S. degree once the requirements for that degree have been fulfilled. See General Requirements in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees)" section of this bulletin and Chemical Engineering's "Master's (p. 4)" section.

**Minimum Grade Requirement**

Any course intended to satisfy the Engineer degree requirements must be taken for a letter grade, if offered. An overall grade point average (GPA) of 3.0 must be maintained.

**Reading Committee Requirement**

All candidates are required to have an initial meeting with their reading committees by the end of their ninth quarter. The committee must have a minimum of two members, both of whom are Chemical Engineering faculty members. The reading committee meetings are intended to be discussion sessions, to help to focus and guide the thesis project; they are not examinations.

Students are responsible for reporting meeting dates to departmental student services.

**Thesis Requirement**

The thesis must represent a substantial piece of research equivalent to nine months of full-time effort and must be approved by the student's reading committee.

**Qualification for the Ph.D. Program by Students Ready to Receive the Degree of Engineer**

After completing the requirements for the Engineer degree, a student may petition to be examined on the research work completed for that degree, for the purpose of qualifying for admission to Ph.D. candidacy. If the petition is approved, the student's thesis must be approved by the reading committee and available in its final form for inspection by the entire faculty at least two weeks prior to the scheduled date of said examination.

**Doctor of Philosophy in Chemical Engineering**

The University's general requirements for the Ph.D. are specified in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees)" section of this bulletin.

The Ph.D. degree is awarded after the completion of a minimum of 135 units of graduate work as well as satisfactory completion of any additional University requirements and the following departmental requirements. Completion of a M.S. degree is not a prerequisite for beginning, pursuing, or completing doctoral work.

**Unit and Course Requirements**

A minimum of 135 completed units is required, including a component of a minimum of 45 units in science and engineering courses, consisting of 42 lecture units and 3 units of CHEMENG 699 Colloquium.

1. CHEMENG 699 should be taken all years each quarter of the academic year; all these units count toward the required 135 units.
2. The research units for CHEMENG 399 count toward the required 135 units, but may not be counted toward the 45 unit component.
3. Students working with a research adviser should enroll each quarter in the 500 series, 600, and 699 as appropriate and as study list unit limits permit. All these seminar and research units are included within the required minimum of 135 units for degree.
Students with questions or issues should contact departmental graduate student services (http://cheme.stanford.edu/about/contact).

The following courses are required:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEMENG 300</td>
<td>Applied Mathematics in the Chemical and Biological Sciences</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 310</td>
<td>Microhydrodynamics</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 320</td>
<td>Chemical Kinetics and Reaction Engineering</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 340</td>
<td>Molecular Thermodynamics</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 345</td>
<td>Fundamentals and Applications of Spectroscopy</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 355</td>
<td>Advanced Biochemical Engineering</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 399</td>
<td>Graduate Research Rotation in Chemical Engineering</td>
<td>1</td>
</tr>
<tr>
<td>CHEMENG 699</td>
<td>Colloquium</td>
<td>1</td>
</tr>
</tbody>
</table>

Plus two courses at the 400 course level; in 2019-20 the following are available:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEMENG 432</td>
<td>Electrochemical Energy Conversion</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 450</td>
<td>Advances in Biotechnology</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 456</td>
<td>Microbial Bioenergy Systems</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 460</td>
<td>Interfacial Engineering of Soft Matter</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 469</td>
<td>Solid Structure and Properties of Polymers</td>
<td>3</td>
</tr>
<tr>
<td>CHEMENG 470</td>
<td>Complex Fluid Interfaces: Capillarity and Interfacial Dynamics</td>
<td>3</td>
</tr>
</tbody>
</table>

These courses are to be taken at Stanford, and any petition to substitute another graduate-level course for any of these core courses must be approved by the department chair. The remaining graduate-level science and engineering lecture courses may be chosen from any department. A student may petition the department chair for approval to include an upper-division undergraduate science or engineering lecture course. All proposals for Ph.D. required course work must be approved by the student’s adviser and the department chair or the chair of the department’s Graduate Curriculum Committee. Students with questions, concerns, or issues should contact student services staff in the department office in Shriram Center, room 129.

Ph.D. students may petition to add a M.S. degree program to their university record; submit in a Graduate Authorization petition in Axess. Once the online petition is approved, the M.S. candidate must complete a Program Proposal for a Master’s Degree form and submit it to departmental student services.

Ph.D. students with a M.S. program apply in Axess for M.S. degree conferral. (See the “Master of Science in Chemical Engineering (p. 4)” section in this bulletin.) The M.S. degree must be awarded within the University’s candidacy period for completion of a master’s degree.

**Minimum Grade Requirement**

Any course intended to satisfy the Ph.D. degree requirements must be taken for a letter grade, if offered. A GPA of 3.0 or above is required by the end of the first year, in order to continue in the Ph.D. program. The overall grade point average (GPA) of at least 3.0 must be maintained.

**Degree Milestones**

Degree milestones indicate progress toward degree. They are listed on unofficial transcripts and document satisfactory and timely completion of various events, such as securing research advisers, candidacy examinations, submission of completed degree progress forms, dates of reading committee meetings, assisting with the teaching CHEMENG courses. Report and submit forms as appropriate to departmental student services. Students with questions or issues should talk with student services staff; students approaching a milestone should be aware of intradepartmental communications and support, and students with concerns should discuss them with student services staff.

**Candidacy**

To be advanced to Ph.D. candidacy, the student must secure a research dissertation adviser (and any required co-adviser), maintain a 3.0 or higher GPA, successfully complete a Ph.D. candidacy examination, and submit a completed Application for Candidacy for Doctoral Degree form.

First, the research adviser and any required co-adviser must be established by the end of the second quarter in the Ph.D. program. Failure to do so leads to termination of a student’s study toward a Ph.D. in Chemical Engineering; however, the student may continue to work toward an M.S. degree (see the “Master of Science in Chemical Engineering (p. 4)” section of this bulletin). Departmental Ph.D. financial support does not continue.

Second, the Ph.D. candidacy examination before a faculty committee is at the end of the fourth quarter. It consists of (a) a student’s oral presentation of their thinking about their research proposal and current progress and (b) an examination by faculty members of the proposal specifics as well as the student’s understanding of the fundamental chemical, physical, and biological concepts that govern the molecular behavior of the system being studied. Upon successful completion of this examination, candidates must submit an Application for Candidacy for Doctoral Degree form, approved by their research adviser(s), to departmental graduate student services within two months.

**Teaching Requirement**

Teaching experience is considered an essential component of pre-doctoral training because it assists in the further development and refinement of candidates’ skills in conveying what they know, think, and conclude, based on articulated assumptions and knowledge. All Ph.D. candidates, regardless of the source of their financial support, are required to assist in the teaching of a minimum of two chemical engineering courses.

**Reading Committee Requirement**

Reading committee meetings are intended to be discussion sessions with all members of the reading committee participating that help to focus and refine the dissertation project; they are not examinations.

By the end of the second year, all Ph.D. candidates are required to assemble reading committees and submit Doctoral Dissertation Reading Committee forms signed by research advisers to student services.

By the end of the first quarter of the third year, candidates are required to have an initial meeting with the complete reading committee. It is the candidate’s responsibility to schedule committee meetings, and the faculty’s to respond in a timely manner to scheduling requests. The composition of the reading committee may be amended; submit appropriate form to student services. Candidates are responsible for reporting meeting dates to departmental student services.

The faculty strongly encourage doctoral candidates to take advantage of the benefits of annual committee meetings, to enable candidates to benefit from this type of open discussion, support, and recommendations from faculty.

**Research Poster Requirement**

Experience in analyzing and presenting one’s research to diverse audiences also is an essential component of predoctoral training, and faculty strongly encourage candidates to do so several times each year, starting in the second year. All candidates in their third year are required to prepare and present a research poster during the annual Mason Lectures week in spring quarter.
Dissertation and Oral Defense Requirements

A dissertation based on a successful investigation of a fundamental problem in chemical engineering is required. A student is expected to have fulfilled all the requirements for this degree, including the completion of a dissertation approved by his or her research adviser(s) and reading committee members within approximately five years after enrolling the Ph.D. program. Upon adviser approval (s), copies of the final draft of the dissertation must be distributed to each reading committee member. No sooner than three weeks after this distribution, a student may schedule an oral examination. This examination is a dissertation defense, based on the candidate’s dissertation research, and is in the form of a public seminar followed by a private examination by the faculty members on the student’s oral examination committee. Satisfactory performance in the oral examination and acceptance of an approved dissertation by Graduate Degree Progress, Office of the University Registrar, leads to Ph.D. degree conferral.

Ph.D. Minor in Chemical Engineering

The University’s general requirements for the Ph.D. minor are specified in the "Graduate Degrees (http://exploredegrees.stanford.edu/graduatedegrees)" section of this bulletin. An application for a Ph.D. minor must be approved by both the major and minor departments.

A student proposing a Ph.D. minor in Chemical Engineering must work with a minor program adviser who has a faculty appointment in Chemical Engineering. This adviser must be included as a member of the student’s reading committee for the doctoral dissertation, and the entire reading committee must meet at least once with the candidate. This meeting should occur at least one year prior to the scheduling of the student’s oral examination; the department strongly prefers that regular meetings of the complete reading committee start in the second year of graduate study. In addition, the Chemical Engineering faculty member who is the minor adviser must be a member of the student’s University oral examination committee.

The Ph.D. minor program must include at least 20 units of graduate-level lecture courses (numbered at the 200 level or above), but may not include any 1-2 unit lecture courses in the 20-unit minimum. The list of courses must form a coherent program and must be approved by the minor program adviser and the chair of this department. All courses for the minor must be taken for a letter grade, and a GPA of at least 3.0 must be earned for these courses.

For a statement of University policy on graduate advising, see the "Graduate Advising (http://exploredegrees.stanford.edu/graduatedegrees/#advisingandcredentialstext)" section of this bulletin.

Ph.D. Student Advising

The Department of Chemical Engineering is committed to providing academic advising in support of doctoral student scholarly and professional development. When most effective, this advising relationship entails collaborative and sustained engagement by both the adviser and the advisee. As a best practice, advising expectations should be periodically discussed and reviewed to ensure mutual understanding. Both the adviser and the advisee are expected to maintain professionalism and integrity.

Finally, graduate students are active contributors to the advising relationship, proactively seeking academic and professional guidance and taking responsibility for informing themselves of policies and degree requirements for their graduate program.

For a statement of University policy on graduate advising, see the "Graduate Advising (http://exploredegrees.stanford.edu/graduatedegrees/#advisingandcredentialstext)" section of this bulletin.

Master's Student Advising

The Department of Chemical Engineering is committed to providing academic advising in support of our M.S. students’ education and professional development. When most effective, this advising relationship entails collaborative engagement by both the adviser and the advisee. As a best practice, advising expectations should be discussed and reviewed to ensure mutual understanding. Both the adviser and the advisee are expected to maintain professionalism and integrity.

At the start of graduate study, normally at the beginning of the Fall quarter, each student is assigned a master’s program adviser: a member of our faculty who will provide guidance in course selection and in exploring academic opportunities and professional pathways. The department’s graduate handbook (https://cheme.stanford.edu/masters-handbook) provides information and suggested timelines for advising meetings. Usually, the same faculty member serves as program adviser for the duration of master’s study, but the handbook does describe a process for formal adviser changes.

In addition, the Director of Graduate Studies (DGS) and the Graduate Committee meets with all the master’s students at the start of the first year, and are available during the academic year by email and during office hours.

Our department's student services office is also an important part of the master’s advising team. They inform students and advisers about university and department requirements, procedures, and opportunities, and they maintain the official records of advising assignments and approvals.

Finally, graduate students are active contributors to the advising relationship, proactively seeking academic and professional guidance and taking responsibility for informing themselves of policies and degree requirements for their graduate program.

For a statement of University policy on graduate advising, see the "Graduate Advising (http://exploredegrees.stanford.edu/graduatedegrees/#advisingandcredentialstext)" section of this bulletin.
teaching pedagogy, navigating policies and degree requirements, and exploring academic opportunities and professional pathways.

The Director of Graduate Studies (DGS) meets with all the doctoral students at the start of the first year, and is available during the academic year by email and during office hours. Our department's student services office is also an important part of the doctoral advising team: they inform students and advisers about university and department requirements, procedures, and opportunities, and they maintain the official records of advising assignments and approvals. Students are encouraged to talk with the DGS and the student services office as they consider adviser selection, or for guidance in working with their adviser(s).

Our doctoral students are active contributors to the advising relationship, proactively seeking academic and professional guidance and taking responsibility for informing themselves of policies and degree requirements for their graduate program.


Emeriti: (Professors) Andreas Acrivos, George M. Homsy, Robert J. Madix, Channing R. Robertson

Chair: Zhenan Bao

Professors: Zhenan Bao, Stacey F. Bent, Curtis W. Frank, Gerald G. Fuller, Chaitan Khosla, Eric S. G. Shaqfeh, Alfred M. Spormann, James R. Swartz

Associate Professors: Alexander R. Dunn, Thomas F. Jaramillo, Elizabeth S. Sattely, Andrew J. Spakowitz

Assistant Professors: Monther Abu-Remaileh, Matteo Cargnello, Xiaojing Gao, Danielle J. Mai, Jian Qin, William A. Tarpeh, Roseanna N. Zia

Courtesy Professors: Lynette S. Cegelski, Jennifer R. Cochran, Sarah C. Heilshorn, Daniel Herschlag, David Myung, Christina D. Smolke, H. Tom Soh, Robert M. Waymouth

Senior Lecturer: Lisa Y. Hwang

Lecturers: Frank Abild-Pedersen, Ricardo B. Levy, Shari B. Libicki, Sara Loesch-Frank, Howard B. Rosen

Adjunct Professors: Ying-Chih Chang, John Mealli, Do Y. Yoon

Cognate Courses for Advanced Degrees in Chemical Engineering

In addition to core CHEMENG graduate courses in the 300 series and elective CHEMENG graduate courses in the 200 and 400 series, students pursuing advanced degrees in chemical engineering include elective courses offered by other departments. The following list is a partial list of the more frequently chosen courses and is subdivided into five focus areas.

<table>
<thead>
<tr>
<th>Units</th>
<th>Courses</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>APPPHYS 207</td>
<td>Laboratory Electronics</td>
</tr>
<tr>
<td>3</td>
<td>CHEM 221</td>
<td>Advanced Organic Chemistry I</td>
</tr>
<tr>
<td>3</td>
<td>CHEM 271</td>
<td>Advanced Physical Chemistry</td>
</tr>
<tr>
<td>3</td>
<td>CHEM 273</td>
<td>Advanced Physical Chemistry</td>
</tr>
<tr>
<td>3</td>
<td>EE 261</td>
<td>The Fourier Transform and Its Applications</td>
</tr>
<tr>
<td>3</td>
<td>STATS 200</td>
<td>Introduction to Statistical Inference</td>
</tr>
<tr>
<td>3</td>
<td>BIOE 331</td>
<td>Protein Engineering</td>
</tr>
</tbody>
</table>

**Broadly Applicable**

<table>
<thead>
<tr>
<th>Units</th>
<th>Courses</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>BIOPHYS/SBIO 241</td>
<td>Biological Macromolecules</td>
</tr>
<tr>
<td>4</td>
<td>CBIO 241</td>
<td>Cellular Basis of Cancer</td>
</tr>
<tr>
<td>4</td>
<td>MCP 256</td>
<td>How Cells Work: Energetics, Compartments, and Coupling in Cell Biology</td>
</tr>
<tr>
<td>3-5</td>
<td>SBIO 241</td>
<td>Biological Macromolecules</td>
</tr>
</tbody>
</table>

**Fluid Mechanics, Applied Mathematics, and Numerical Analysis focus**

<table>
<thead>
<tr>
<th>Units</th>
<th>Courses</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>AA 218</td>
<td>Introduction to Symmetry Analysis</td>
</tr>
<tr>
<td>3</td>
<td>CME 200</td>
<td>Linear Algebra with Application to Engineering Computations</td>
</tr>
<tr>
<td>3</td>
<td>CME 204</td>
<td>Partial Differential Equations in Engineering</td>
</tr>
<tr>
<td>3</td>
<td>CME 206</td>
<td>Introduction to Numerical Methods for Engineering</td>
</tr>
<tr>
<td>3</td>
<td>CME 212</td>
<td>Advanced Software Development for Scientists and Engineers</td>
</tr>
<tr>
<td>3</td>
<td>ME 351A</td>
<td>Fluid Mechanics</td>
</tr>
<tr>
<td>3</td>
<td>ME 457</td>
<td>Fluid Flow in Microdevices</td>
</tr>
</tbody>
</table>

**Materials Science focus**

<table>
<thead>
<tr>
<th>Units</th>
<th>Courses</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>MATSCI 210</td>
<td>Organic and Biological Materials</td>
</tr>
<tr>
<td>3</td>
<td>MATSCI 251</td>
<td>Microstructure and Mechanical Properties</td>
</tr>
<tr>
<td>3</td>
<td>MATSCI 316</td>
<td>Nanoscale Science, Engineering, and Technology</td>
</tr>
<tr>
<td>3</td>
<td>MATSCI 343</td>
<td>Organic Semiconductors for Electronics and Photonics</td>
</tr>
<tr>
<td>3</td>
<td>MATSCI 380</td>
<td>Nano-Biotechnology</td>
</tr>
</tbody>
</table>

**Microelectronics focus**

<table>
<thead>
<tr>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td>3</td>
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<td>Linear Algebra with Application to Engineering Computations</td>
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<td>3</td>
<td>CME 204</td>
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<td>CME 212</td>
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<td>3</td>
<td>ME 457</td>
<td>Fluid Flow in Microdevices</td>
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**Microelectronics focus**

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</tr>
<tr>
<td>3</td>
<td>ME 457</td>
<td>Fluid Flow in Microdevices</td>
</tr>
</tbody>
</table>

* e.g., with CHEMENG 281 Biochemistry I, CHEMENG 283 Biochemistry II, CHEMENG 454 Synthetic Biology and Metabolic Engineering, CHEMENG 456 Microbial Bioenergy Systems.

** e.g., with CHEMENG 462 Complex Fluids and Non-Newtonian Flows.

*** e.g., with CHEMENG 442 Suspension Mechanics, CHEMENG 464 Polymer Chemistry, CHEMENG 466 Polymer Physics.

**** e.g., with CHEMENG 240 Micro and Nanoscale Fabrication Engineering.