

CHEMICAL ENGINEERING

Courses offered by the Department of Chemical Engineering are listed under the subject code CHEMENG on the (<https://explorecourses.stanford.edu/search/?q=CHEMENG&view=catalog&page=0&academicYear=&filter-term-Autumn=on&filter-term-Winter=on&filter-term-Spring=on&filter-term-Summer=on&collapse=&filter-departmentcode=CHEMENG=on&filter-catalognumber=CHEMENG=on&filter-coursestatus=Active=on&filter-catalognumber=CHEMENG=on>) *Stanford Bulletin's* ExploreCourses web site.

Research investigations are currently being carried out in the following fields: applied statistical mechanics, biocatalysis, 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>.

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>). 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/>) 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://exploreddegrees.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, biocatalysis, biochemical engineering, bioengineering, biophysics, computational materials science, colloid science, dynamics of complex fluids, energy conversion, functional genomics, hydrodynamic stability, kinetics and catalysis, microrheology, 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> (<https://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 conferral 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

	Units
Mathematics (24-30 units)¹	10
The following sequence or approved AP credit	
MATH 19	Calculus
MATH 20	Calculus
MATH 21	Calculus
Select one of the following:	5-10
CME 100	Vector Calculus for Engineers
MATH 51 & MATH 52	Linear Algebra, Multivariable Calculus, and Modern Applications and Integral Calculus of Several Variables
Select one of the following:	5
CME 102	Ordinary Differential Equations for Engineers
or MATH 53	Ordinary Differential Equations with Linear Algebra
Select one of the following:	4-5
CME 104	Linear Algebra and Partial Differential Equations for Engineers
or CME 106	Introduction to Probability and Statistics for Engineers
Science (23-29 units)¹	
CHEM 31M	Chemical Principles: From Molecules to Solids
CHEM 33	Structure and Reactivity of Organic Molecules
CHEM 121	Understanding the Natural and Unnatural World through Chemistry
PHYSICS 41	Mechanics
or PHYSICS 41E	Mechanics, Concepts, Calculations, and Context
PHYSICS 43	Electricity and Magnetism
Technology in Society (3-5 units)	
One course required, see Basic Requirement 4; course chosen must be on the SoE-Approved Courses list at ughb.stanford.edu the year taken.	3-5
Engineering Fundamentals (7-9 units)	
Two courses minimum; see Basic Requirement 3	
CHEMENG/ENGR 20	Introduction to Chemical Engineering
Fundamentals Elective from another School of Engineering department	3-5
See the UGHB for a list of courses.	
Chemical Engineering Depth (51 units minimum)	
CHEMENG 100	Chemical Process Modeling, Dynamics, and Control
CHEMENG 110A	Introduction to Chemical Engineering Thermodynamics ³
CHEMENG 110B	Multi-Component and Multi-Phase Thermodynamics
CHEMENG 120A	Fluid Mechanics
CHEMENG 120B	Energy and Mass Transport
CHEMENG 130A	Microkinetics - Molecular Principles of Chemical Kinetics
CHEMENG 130B	Introduction to kinetics and reactor design
CHEMENG 150	Biochemical Engineering
CHEMENG 180	Chemical Engineering Plant Design
CHEMENG 181	Biochemistry I

CHEMENG 185A	Chemical Engineering Laboratory A (WIM)	5
CHEMENG 185B	Chemical Engineering Laboratory B	5
CHEM 171	Foundations of Physical Chemistry ⁴	4
Select 1 of the following:		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 190	Undergraduate Research in Chemical Engineering	
CHEMENG 190H	Undergraduate Honors Research in Chemical Engineering	
CHEMENG 196	Creating and Leading New Ventures in Engineering and Science-based Industries	
Total Units		108-118

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 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.

³ Students who completed CHEM 171 prior to academic year 2020-21 may substitute CHEMENG 110A with CHEM 171.

⁴ Students who completed CHEM 173 prior to academic year 2020-21 may substitute CHEM 171 with CHEM 173.

* 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 2020-2021 deadline is March 1, 2021. 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/00/research_opps/Grants (http://ual.stanford.edu/00/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 5, 2021, 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, 2021, 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 2020-2021 deadline is May 3, 2021.
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:

		Units
ENGR 20	Introduction to Chemical Engineering	4
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 130B	Introduction to kinetics and reactor design	3
CHEMENG 185A	Chemical Engineering Laboratory A	5
CHEMENG 180	Chemical Engineering Plant Design	4
Select one of the following:		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 181	Biochemistry I	
Total Units		36

- 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.

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.

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.

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.

May select from:		Units
CHEMENG 300	Applied Mathematics in the Chemical and Biological Sciences	3
CHEMENG 310	Microhydrodynamics	3
CHEMENG 320	Chemical Kinetics and Reaction Engineering	3
CHEMENG 340	Molecular Thermodynamics	3
CHEMENG 345	Fundamentals and Applications of Spectroscopy	3
CHEMENG 355	Advanced Biochemical Engineering	3

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.

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://exploreddegrees.stanford.edu/cotermdegrees/>)" section. University requirements for the master's degree are described in the "Graduate Degrees (<http://exploreddegrees.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 advisor 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:

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

May select from:		Units
CHEMENG 300	Applied Mathematics in the Chemical and Biological Sciences	3
CHEMENG 310	Microhydrodynamics	3
CHEMENG 320	Chemical Kinetics and Reaction Engineering	3

CHEMENG 340	Molecular Thermodynamics	3
CHEMENG 345	Fundamentals and Applications of Spectroscopy	3
CHEMENG 355	Advanced Biochemical Engineering	3

- 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.

		Units
CHEMENG 242	Basic Principles of Heterogeneous Catalysis with Applications in Energy Transformations	3
CHEMENG 250	Biochemical Engineering	3
CHEMENG 260	Polymer Science and Engineering	3
CHEMENG 277	Data Science and Machine Learning Approaches in Chemical and Materials Engineering	3
CHEMENG 283	Biochemistry II	3
CHEMENG 296	Creating and Leading New Ventures in Engineering and Science-based Industries	3
CHEMENG 432	Electrochemical Energy Conversion	3
CHEMENG 443	Principles and practice of heterogeneous catalysis	3
CHEMENG 450	Advances in Biotechnology	3

- HCP students may use any of the following to satisfy this requirement:
 - Three (3) units of CHEMENG 699 Colloquium.
 - Three (3) units of a seminar/speaker series in engineering, science, or math.
 - A three-unit graduate course in engineering, science, or math.
- 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:

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

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.

		Units
CHEMENG 300	Applied Mathematics in the Chemical and Biological Sciences	3
CHEMENG 310	Microhydrodynamics	3
CHEMENG 320	Chemical Kinetics and Reaction Engineering	3
CHEMENG 340	Molecular Thermodynamics	3
CHEMENG 345	Fundamentals and Applications of Spectroscopy	3
CHEMENG 355	Advanced Biochemical Engineering	3
Plus 3 units of:		
CHEMENG 699	Colloquium	1

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://exploreddegrees.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://exploreddegrees.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:

		Units
CHEMENG 300	Applied Mathematics in the Chemical and Biological Sciences	3

CHEMENG 310	Microhydrodynamics	3
CHEMENG 320	Chemical Kinetics and Reaction Engineering	3
CHEMENG 340	Molecular Thermodynamics	3
CHEMENG 345	Fundamentals and Applications of Spectroscopy	3
CHEMENG 355	Advanced Biochemical Engineering	3
CHEMENG 399	Graduate Research Rotation in Chemical Engineering	1
CHEMENG 699	Colloquium	1
Plus two courses at the 400 course level; in 2020-21 the following are available:		
CHEMENG 424	Structure and Reactivity of Solid Surfaces	3
CHEMENG 432	Electrochemical Energy Conversion	3
CHEMENG 443	Principles and practice of heterogeneous catalysis	3
CHEMENG 450	Advances in Biotechnology	3
CHEMENG 456	Microbial Bioenergy Systems	3

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 by the end of the fifth quarter. It consists of (a) a student's written research perspective and 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://exploreddegrees.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.

COVID-19 Policies

On July 30, the Academic Senate adopted grading policies effective for all undergraduate and graduate programs, excepting the professional Graduate School of Business, School of Law, and the School of Medicine M.D. Program. For a complete list of those and other academic policies relating to the pandemic, see the "COVID-19 and Academic Continuity (<http://exploreddegrees.stanford.edu/covid-19-policy-changes/#tempdeptemplatetabtext>)" section of this bulletin.

The Senate decided that all undergraduate and graduate courses offered for a letter grade must also offer students the option of taking the course for a "credit" or "no credit" grade and recommended that deans, departments, and programs consider adopting local policies to count courses taken for a "credit" or "satisfactory" grade toward the fulfillment of degree-program requirements and/or alter program requirements as appropriate.

Undergraduate Degree Requirements

Grading

The Department of Chemical Engineering counts all courses taken in academic year 2020-21 with a grade of 'CR' (credit) or 'S' (satisfactory) towards satisfaction of undergraduate degree requirements that otherwise require a letter grade.

Graduate Degree Requirements

Grading

The Department of Chemical Engineering counts all courses taken in academic year 2020-21 with a grade of 'CR' (credit) or 'S' (satisfactory) towards satisfaction of graduate degree requirements that otherwise require a letter grade provided that the instructor affirms that the work was done at a 'B-' or better level.

Students enrolled in the doctoral program must take core course requirements (CHEMENG 300-level and 400-level) for a letter grade. Exceptions to this policy will be reviewed by the Chemical Engineering Department's Graduate Curriculum Committee on a case-by-case basis.

For a statement of University policy on graduate advising, see the "Graduate Advising (<http://exploreddegrees.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://exploreddegrees.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.

Faculty advisers guide students in key areas such as selecting courses, designing and conducting research, developing of teaching pedagogy, navigating policies and degree requirements, and exploring academic opportunities and professional pathways. The department's graduate handbook provides information and suggested timelines for advising meetings in the different stages of the doctoral program.

Ph.D. students are initially assigned a program adviser at the outset of their matriculation at Stanford. This faculty member will provide initial guidance in course selection, in exploring academic opportunities and professional pathways, and in identifying doctoral research opportunities. The department does require formal lab rotations during two quarters prior to selecting a doctoral research/thesis adviser.

Graduate students are expected to select a thesis adviser before the end of the first year of the program. Students are encouraged to work collaboratively with their adviser to establish a dissertation project and form a Dissertation Reading Committee. Advancement to doctoral candidacy is expected to occur prior to the end of the fourth quarter of the program. The process and timing of adviser selection is described in the Graduate Academic Policies and Procedures (GAP) (<https://gap.stanford.edu/handbooks/gap-handbook/chapter-3/subchapter-3/page-3-3-1/>). The research supervisor assumes primary responsibility for the future direction of the student, taking on the roles previously filled by the program adviser, and will ultimately direct the student's dissertation. Most students find an adviser from among the primary faculty members of our department. However, the research adviser may be a faculty member from another Stanford department who is familiar with supervising doctoral students and able to provide both advising and funding for the duration of the doctoral program. When the research adviser is from outside our department, the student will also identify a program adviser from our primary faculty, to provide guidance on departmental requirements and opportunities. Thesis advisers are expected to meet with graduate students at least once each year to discuss and help develop the student's program plan. Additionally, advisers and students should meet on a regular basis throughout the year to discuss the student's professional development in key areas such as selecting courses, designing and conducting research, developing 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.

Additionally, the program adheres to the advising guidelines and responsibilities listed by the Office of the Vice Provost for Graduate Education (<https://vpge.stanford.edu/academic-guidance/advising-mentoring/>) (VPGE) and in the Graduate Academic Policies (<https://gap.stanford.edu/handbooks/gap-handbook/chapter-3/subchapter-3/page-3-3-1/>) (GAP).

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, Andrew J. Spakowitz, Alfred M. Spormann, James R. Swartz

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

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, Meagen Mauter, David Myung, H. Tom Soh, Robert M. Waymouth

Senior Lecturer: Lisa Y. Hwang

Lecturers: Ricardo B. Levy, Howard B. Rosen

Adjunct Lecturer: Sara Loesch-Frank

Adjunct Professors: Ying-Chih Chang, Shari B. Libicki, John Moalli, 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.

	Units
Broadly Applicable	
APPPHYS 207	Laboratory Electronics 4
CHEM 221	Advanced Organic Chemistry I 3
CHEM 271	Advanced Physical Chemistry 3
CHEM 273	Advanced Physical Chemistry 3
EE 261	The Fourier Transform and Its Applications 3
STATS 200	Introduction to Statistical Inference 4
Biochemistry and Bioengineering focus*	
BIOE 331	Protein Engineering 3
BIOPHYS/SBIO 241	Biological Macromolecules 5
CBIO 241	Cellular Basis of Cancer 4
MCP 256	How Cells Work: Energetics, Compartments, and Coupling in Cell Biology 4
SBIO 241	Biological Macromolecules 5
Fluid Mechanics, Applied Mathematics, and Numerical Analysis focus**	
AA 218	Introduction to Symmetry Analysis 3
CME 200	Linear Algebra with Application to Engineering Computations 3
CME 204	Partial Differential Equations in Engineering 3
CME 206	Introduction to Numerical Methods for Engineering 3
CME 212	Advanced Software Development for Scientists and Engineers 3
ME 351A	Fluid Mechanics 3
ME 457	Fluid Flow in Microdevices 3
Materials Science focus***	
MATSCI 210	Organic and Biological Materials 3
MATSCI 251	Microstructure and Mechanical Properties 3
MATSCI 316	Nanoscale Science, Engineering, and Technology 3

MATSCI 343	Organic Semiconductors for Electronics and Photonics	3
MATSCI 380	Nano-Biotechnology ****	3
Microelectronics focus		
AA 218	Introduction to Symmetry Analysis	3
CME 200	Linear Algebra with Application to Engineering Computations	3
CME 204	Partial Differential Equations in Engineering	3
CME 206	Introduction to Numerical Methods for Engineering	3
CME 212	Advanced Software Development for Scientists and Engineers	3
ME 457	Fluid Flow in Microdevices	3
Microelectronics focus		
AA 218	Introduction to Symmetry Analysis	3
CME 200	Linear Algebra with Application to Engineering Computations	3
CME 204	Partial Differential Equations in Engineering	3
CME 206	Introduction to Numerical Methods for Engineering	3
CME 212	Advanced Software Development for Scientists and Engineers	3
ME 457	Fluid Flow in Microdevices	3

* 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.

Courses

CHEMENG 10. The Chemical Engineering Profession. 1 Unit.

Open to all undergraduates. Overview of and careers in chemical engineering; opportunities to develop networks with working professionals. Panel discussions on career paths and post-graduation opportunities available. Areas include biotechnology, electronics, energy, environment, management consulting, nanotechnology, and graduate school in business, law, medicine, and engineering.

CHEMENG 12SC. An Exploration of Art Materials: The Intersection of Art and Science. 2 Units.

There is growing interest in the intersection of art and science, whether from artists adapting technology to suit their visions or from scientists and engineers seeking to explain various visual effects. To take advantage of possible creative sparks at the art/science interface, it is necessary for fuzzies and techies to have some knowledge of the language used by the other side. This interface will be explored through examining approaches used by an artist and an engineer in the context of the materials science of cultural objects. In-class lectures, hands-on studio practice, and field trips will be used to illustrate these different perspectives. At the heart of the scientific approach is the notion that a cultural object, e.g., a painting, is a physical entity comprising materials with different physical properties and different responses to environmental stresses presented by light, heat, and water. In support of this outlook, in-class lectures and discussions will focus on the basic concepts of color, optics, mechanics, composite structures, and response of the object to environmental stress, and we will visit Bay Area museums to see how artists employ such techniques. The hands-on studio experience is designed to increase students' confidence and develop their appreciation of differences in materials. It is not necessary to have any artistic training, only a willingness to experiment. The in-class studio projects will include working with line and shadow; color, binders, and mordants; global sources of pigments; substrates and writing; and material failure. Students will make one technical presentation on a topic in one of the five areas relevant to a painting: color, optics, mechanics, composites, and stress response. In addition, they will prepare one essay on the issues surrounding the intersection of art and science. Finally, they will complete a project related to one of the thematic areas covered in the hands-on studio sessions and make a final oral presentation describing their project.

CHEMENG 20. Introduction to Chemical Engineering. 4 Units.

Overview of chemical engineering through discussion and engineering analysis of physical and chemical processes. Topics: overall staged separations, material and energy balances, concepts of rate processes, energy and mass transport, and kinetics of chemical reactions. Applications of these concepts to areas of current technological importance: biotechnology, energy, production of chemicals, materials processing, and purification. Prerequisite: CHEM 31. Same as: ENGR 20

CHEMENG 31N. When Chemistry Meets Engineering. 3 Units.

Preference to freshmen. Chemistry and engineering are subjects that are ubiquitous around us. But what happens when the two meet? Students will explore this question by diving into experimental problems that scientists and engineers have to face on a daily basis. Many processes that are taken for granted have been developed by understanding science at a very fundamental level and then applying it to large and important industrial processes. In this seminar, students will explore some of the basic concepts that are important to address chemical engineering problems through experimental work. Students will build materials for energy and environmental applications, understand how to separate mixtures into pure compounds, produce fuels, and will learn to look at the chemical properties of molecules that are part of daily life with a different eye.

CHEMENG 60Q. Environmental Regulation and Policy. 3 Units.

Preference to sophomores. How does government, politics and science affect environmental policy? We examine environmental policy including the precautionary principal, acceptable risks, mathematical models, and cost-effectiveness of regulation. You will learn how data is changing environmental regulation and how different administrations mold environmental policy in real-time. We examine the use of science and engineering, its media presentation and misrepresentation, and the effect of public scientific and technical literacy. You will learn how to participate in the process and effect change.

CHEMENG 90Q. Dare to Care: Compassionate Design. 3 Units.

Imagine yourself with your abundant creativity, intellect, and passion, but your ability to move or speak is diminished. How would you face the world, how would you thrive at Stanford, how would you relay to people your ideas and creations? How would you share yourself and your ideas with the world? There are more than 50 million individuals in America with at least one disability, and in the current world of design, these differences are often overlooked. How do we as designers empower people of diverse physical abilities and provide them with means of self-expression? In Compassionate Design, students from any prospective major are invited to explore the engineering design process by examining the needs of persons with disabilities. Through invited guests, students will have the opportunity to directly engage people with different types of disabilities as a foundation to design products that address problems of motion and mobility, vision, speech and hearing. For example, in class, students will interview people who are deaf, blind, have cerebral palsy, or other disabling conditions. Students will then be asked, using the design tools they have been exposed to as part of the seminar, to create a particular component or device that enhances the quality of life for that user or users with similar limitations. Presentation skills are taught and emphasized as students will convey their designs to the class and instructors. Students will complete this seminar with a compassionate view toward design for the disabled, they will acquire a set of design tools that they can use to empower themselves and others in whatever direction they choose to go, and they will have increased confidence and abilities in presenting in front of an audience.

CHEMENG 100. Chemical Process Modeling, Dynamics, and Control. 3 Units.

Mathematical methods applied to engineering problems using chemical engineering examples. The development of mathematical models to describe chemical process dynamic behavior. Analytical and computer simulation techniques for the solution of ordinary differential equations. Dynamic behavior of linear first- and second-order systems. Introduction to process control. Dynamics and stability of controlled systems. Prerequisites: CHEMENG 20 or ENGR 20; CME 102 or MATH 53.

CHEMENG 110A. Introduction to Chemical Engineering Thermodynamics. 3 Units.

Thermodynamics of single-component systems: laws of thermodynamics, thermodynamic properties, equations of state, properties of ideal and real fluids, phase transitions and phase equilibrium, design of thermodynamic processes including refrigeration and power cycles. This course is intended for undergraduate sophomores and juniors in engineering and/or the chemical sciences; first-year students require consent of instructor. Pre-/Corequisites: CHEM 33, PHYS 41, MATH 51 or CME 100.

CHEMENG 110B. Multi-Component and Multi-Phase Thermodynamics. 3 Units.

Thermodynamic properties, equations of state, properties of non-ideal systems including mixtures, and phase and chemical equilibria. Prerequisite: CHEMENG 110A or equivalent.

CHEMENG 120A. Fluid Mechanics. 4 Units.

The flow of isothermal fluids from a momentum transport viewpoint. Continuum hypothesis, scalar and vector fields, fluid statics, non-Newtonian fluids, shell momentum balances, equations of motion and the Navier-Stokes equations, creeping and potential flow, parallel and nearly parallel flows, time-dependent parallel flows, boundary layer theory and separation, introduction to drag correlations. Prerequisites: junior in Chemical Engineering or consent of instructor; CHEMENG 100 and CME 102 or equivalent.

CHEMENG 120B. Energy and Mass Transport. 4 Units.

General diffusive transport, heat transport by conduction, Fourier's law, conduction in composites with analogies to electrical circuits, advection-diffusion equations, forced convection, boundary layer heat transport via forced convection in laminar flow, forced convection correlations, free convection, free convection boundary layers, free convection correlations and application to geophysical flows, melting and heat transfer at interfaces, radiation, diffusive transport of mass for dilute and non-dilute transfer, mass and heat transport analogies, mass transport with bulk chemical reaction, mass transport with interfacial chemical reaction, evaporation. Prerequisite CHEMENG 120A or consent of instructor.

CHEMENG 130A. Microkinetics - Molecular Principles of Chemical Kinetics. 3 Units.

This course will cover the basis of chemical kinetics that are used to design chemical processes and reactor design. Topics include: origin of rate expression in chemical reactions; experimental generation and analysis of kinetic data; relationship between kinetic and thermodynamic quantities; concepts of elementary steps and reaction orders; reactions in parallel and in sequence; branched reactions; collision theory and introduction to transition state theory; heterogeneous catalysis and surface reactions; enzymatic catalysis; applications of kinetics. Prerequisite CHEMENG 110B or consent of instructor.

CHEMENG 130B. Introduction to kinetics and reactor design. 3 Units.

Introduction to kinetics and reactor design. Identification and comparison of different reactors. Application of rate laws, pseudo steady-state, quasi-equilibrium, and other non-reactive components to develop mathematical models describing different types of reactor systems. Analysis of reaction kinetics in the context of reactor design, and determination of rate laws and reaction mechanisms. Assessment and troubleshooting of reactors by identifying sources of deviations. Application of concepts of reactor design to questions in different fields such as ecology and epidemiology. Prerequisites: 130A or equivalent.

CHEMENG 140. Micro and Nanoscale Fabrication Engineering. 3 Units.

(Same as CHEMENG 140) Survey of fabrication and processing technologies in industrial sectors, such as semiconductor, biotechnology, and energy. Chemistry and transport of electronic and energy device fabrication. Solid state materials, electronic devices and chemical processes including crystal growth, chemical vapor deposition, etching, oxidation, doping, diffusion, thin film deposition, plasma processing. Micro and nanopatterning involving photolithography, unconventional soft lithography and self assembly. Recommended: CHEM 33, 171, and PHYSICS 55.

Same as: CHEMENG 240

CHEMENG 142. Basic Principles of Heterogeneous Catalysis with Applications in Energy Transformations. 3 Units.

(Formerly 124/224) Introduction to heterogeneous catalysis, including models of surface reactivity, surface equilibria, kinetics of surface reactions, electronic and geometrical effects in heterogeneous catalysis, trends in reactivity, catalyst structure and composition, electro-catalysis and photo-catalysis. Selected applications and challenges in energy transformations will be discussed. Prerequisites: CHEM 31AB or 31X, CHEM 171, CHEM 175 or CHEMENG 170 or equivalents. Recommended: CHEM 173.

Same as: CHEMENG 242

CHEMENG 150. Biochemical Engineering. 3 Units.

Combines biological knowledge and methods with quantitative engineering principles. Quantitative review of biochemistry and metabolism as well as recombinant DNA technology and synthetic biology (metabolic engineering). The course begins with a review of basic cell biology, proceeds to bioprocess design and development, and ends with applied synthetic biology methods and examples. Prerequisite: CHEMENG 181 or equivalent.

Same as: BIOE 150, CHEMENG 250

CHEMENG 160. Polymer Science and Engineering. 3 Units.

Interrelationships among molecular structure, morphology, and mechanical behavior of polymers. Topics include amorphous and semicrystalline polymers, glass transitions, rubber elasticity, linear viscoelasticity, and rheology. Applications of polymers in biomedical devices and microelectronics. Prerequisites: CHEM 33 and 171, or equivalent.

Same as: CHEMENG 260

CHEMENG 174. Environmental Microbiology I. 3 Units.

Basics of microbiology and biochemistry. The biochemical and biophysical principles of biochemical reactions, energetics, and mechanisms of energy conservation. Diversity of microbial catabolism, flow of organic matter in nature: the carbon cycle, and biogeochemical cycles. Bacterial physiology, phylogeny, and the ecology of microbes in soil and marine sediments, bacterial adhesion, and biofilm formation. Microbes in the degradation of pollutants. Prerequisites: CHEM 33, CHEM 121 (formerly CHEM 35), and BIOSCI 83, CHEMENG 181, or equivalents. Same as: BIO 273A, CEE 274A, CHEMENG 274

CHEMENG 177. Data Science and Machine Learning Approaches in Chemical and Materials Engineering. 3 Units.

Application of Data Science, Statistical Learning, and Machine Learning approaches to modern problems in Chemical and Materials Engineering. This course develops data science approaches, including their foundational mathematical and statistical basis, and applies these methods to data sets of limited size and precision. Methods for regression and clustering will be developed and applied, with an emphasis on validation and error quantification. Techniques that will be developed include linear and nonlinear regression, clustering and logistic regression, dimensionality reduction, unsupervised learning, neural networks, and hidden Markov models. These methods will be applied to a range of engineering problems, including conducting polymers, water purification membranes, battery materials, disease outcome prediction, genomic analysis, organic synthesis, and quality control in manufacturing. Prerequisites: CS 106A or permission from instructor. Same as: CHEMENG 277, MATSCI 166, MATSCI 176

CHEMENG 180. Chemical Engineering Plant Design. 4 Units.

Open to seniors in chemical engineering or by consent of instructor. Application of chemical engineering principles to the design of practical plants for the manufacture of chemicals and related materials. Topics: flow-sheet development from a conceptual design, equipment design for distillation, chemical reactions, heat transfer, pumping, and compression; estimation of capital expenditures and production costs; plant construction.

CHEMENG 181. Biochemistry I. 4 Units.

Structure and function of major classes of biomolecules, including proteins, carbohydrates and lipids. Mechanistic analysis of properties of proteins including catalysis, signal transduction and membrane transport. Students will also learn to critically analyze data from the primary biochemical literature. Satisfies Central Menu Area 1 for Bio majors. Prerequisites: Chem 121 (formerly 35). Same as: CHEM 181, CHEMENG 281

CHEMENG 183. Biochemistry II. 3 Units.

Focus on metabolic biochemistry: the study of chemical reactions that provide the cell with the energy and raw materials necessary for life. Topics include glycolysis, gluconeogenesis, the citric acid cycle, oxidative phosphorylation, photosynthesis, the pentose phosphate pathway, and the metabolism of glycogen, fatty acids, amino acids, and nucleotides as well as the macromolecular machines that synthesize RNA, DNA, and proteins. Medical relevance is emphasized throughout. Satisfies Central Menu Area 1 for Bio majors. Prerequisite: CHEM 181 or CHEM 141 or CHEMENG 181/281. Same as: CHEM 183, CHEMENG 283

CHEMENG 185A. Chemical Engineering Laboratory A. 5 Units.

This is the first course in a two-quarter sequence that focuses on critical thinking in experimental aspects of chemical engineering. Critical thinking skills will be developed and practiced through guided lab modules with an emphasis on experimental design, data analysis, and technical communication. In addition to lectures, students are required to attend a weekly lab discussion section (approximately 1 hour each) to be scheduled near the start of the quarter. Due to COVID19 circumstances, all course activities will be held online. TAs will conduct experimental work in the lab based on student input on experimental design, and students will be able to view videos showing the sample preparation and data acquisition processes asynchronously. Students will also work in teams to prepare initial project proposals to be carried out in the following quarter in CHEMENG185B. Satisfies the Writing in the Major (WIM) requirement. Prerequisites: CHEMENG 120A, CHEMENG 120B, CHEMENG 130B, and CHEMENG 181.

CHEMENG 185B. Chemical Engineering Laboratory B. 5 Units.

This is the second course in a two-quarter sequence that focuses on critical thinking in experimental aspects of chemical engineering. Students will work in teams to prepare and revise project proposals with an emphasis on analyzing engineered systems to identify key unanswered questions. Students will develop and practice skills related to effective teamwork and communication. Due to COVID19 circumstances, all course activities will be held online. Prerequisite: CHEMENG 185A.

CHEMENG 190. Undergraduate Research in Chemical Engineering. 1-6 Unit.

Laboratory or theoretical work for undergraduates under the supervision of a faculty member. Research in one of the graduate research groups or other special projects in the undergraduate chemical engineering lab. Students should consult advisers for information on available projects. Course may be repeated.

CHEMENG 190H. Undergraduate Honors Research in Chemical Engineering. 1-5 Unit.

For Chemical Engineering majors pursuing a B.S. with Honors degree who have submitted an approved research proposal to the department. Unofficial transcript must document BSH status and at least 9 units of 190H research for a minimum of 3 quarters. May be repeated for credit.

CHEMENG 191H. Undergraduate Honors Seminar. 1 Unit.

For Chemical Engineering majors approved for B.S. with Honors research program. Honors research proposal must be submitted and unofficial transcript document BSH status prior to required concurrent registration in 190H and 191H. May be repeated for credit. Corequisite: 190H.

CHEMENG 193. Interdisciplinary Approaches to Human Health Research. 1 Unit.

For undergraduate students participating in the Stanford ChEM-H Undergraduate Scholars Program. This course will expose students to interdisciplinary research questions and approaches that span chemistry, engineering, biology, and medicine. Focus is on the development and practice of scientific reading, writing, and presentation skills intended to complement hands-on laboratory research. Students will read scientific articles, write research proposals, make posters, and give presentations. Same as: BIO 193, BIOE 193, CHEM 193

CHEMENG 196. Creating and Leading New Ventures in Engineering and Science-based Industries. 3 Units.

Open to seniors and graduate students interested in the creation of new ventures and entrepreneurship in engineering and science intensive industries such as chemical, energy, materials, bioengineering, environmental, clean-tech, pharmaceuticals, medical, and biotechnology. Exploration of the dynamics, complexity, and challenges that define creating new ventures, particularly in industries that require long development times, large investments, integration across a wide range of technical and non-technical disciplines, and the creation and protection of intellectual property. Covers business basics, opportunity viability, creating start-ups, entrepreneurial leadership, and entrepreneurship as a career. Teaching methods include lectures, case studies, guest speakers, and individual and team projects.

Same as: CHEM 196, CHEM 296, CHEMENG 296

CHEMENG 199. Undergraduate Practical Training. 1 Unit.

Only for undergraduate students majoring in Chemical Engineering. Students obtain employment in a relevant industrial or research activity to enhance their professional experience. Students submit a concise report detailing work activities, problems worked on, and key results. May be repeated for credit up to 3 units. Prerequisite: qualified offer of employment and consent of department. Prior approval by the Chemical Engineering Department is required; you must contact the Chemical Engineering Department's Student Services staff for instructions before being granted permission to enroll.

CHEMENG 240. Micro and Nanoscale Fabrication Engineering. 3 Units.

(Same as CHEMENG 140) Survey of fabrication and processing technologies in industrial sectors, such as semiconductor, biotechnology, and energy. Chemistry and transport of electronic and energy device fabrication. Solid state materials, electronic devices and chemical processes including crystal growth, chemical vapor deposition, etching, oxidation, doping, diffusion, thin film deposition, plasma processing. Micro and nanopatterning involving photolithography, unconventional soft lithography and self assembly. Recommended: CHEM 33, 171, and PHYSICS 55.

Same as: CHEMENG 140

CHEMENG 242. Basic Principles of Heterogeneous Catalysis with Applications in Energy Transformations. 3 Units.

(Formerly 124/224) Introduction to heterogeneous catalysis, including models of surface reactivity, surface equilibria, kinetics of surface reactions, electronic and geometrical effects in heterogeneous catalysis, trends in reactivity, catalyst structure and composition, electro-catalysis and photo-catalysis. Selected applications and challenges in energy transformations will be discussed. Prerequisites: CHEM 31AB or 31X, CHEM 171, CHEM 175 or CHEMENG 170 or equivalents. Recommended: CHEM 173.

Same as: CHEMENG 142

CHEMENG 250. Biochemical Engineering. 3 Units.

Combines biological knowledge and methods with quantitative engineering principles. Quantitative review of biochemistry and metabolism as well as recombinant DNA technology and synthetic biology (metabolic engineering). The course begins with a review of basic cell biology, proceeds to bioprocess design and development, and ends with applied synthetic biology methods and examples. Prerequisite: CHEMENG 181 or equivalent.

Same as: BIOE 150, CHEMENG 150

CHEMENG 260. Polymer Science and Engineering. 3 Units.

Interrelationships among molecular structure, morphology, and mechanical behavior of polymers. Topics include amorphous and semicrystalline polymers, glass transitions, rubber elasticity, linear viscoelasticity, and rheology. Applications of polymers in biomedical devices and microelectronics. Prerequisites: CHEM 33 and 171, or equivalent.

Same as: CHEMENG 160

CHEMENG 270. Mechanics of Soft Matter: Rheology. 3 Units.

Soft matter comes in many forms and includes polymeric materials, suspensions, emulsions, foams, gels, and living tissue. These materials are characterized by being easily deformed and possessing internal relaxation time spectra. They are viscoelastic with responses that are intermediate between purely viscous liquids and perfectly elastic solids. This course provides an introduction to the subject of rheology, which concerns the deformation and flow of complex liquids and solids. Rheological testing is aimed at determining the relationships between the applied stresses in these materials and the resulting deformations. These are characterized by material functions, such as viscosity (shear and extensional), moduli, and compliances. These functions reflect the microstructure of the material being tested and microstructural models of polymers (single chain theories and reptation-based models), suspensions, emulsions, and foams will be presented. Experimental methods to measure materials subjected to both shearing and elongational deformations will be described. Many soft matter systems are influenced by interfacial phenomena (foams, emulsions, thin films in the human body) and interfacial rheological techniques will be discussed. Advanced undergraduates register for 270; graduates register for 470. Prerequisites: ChE 120A or its equivalent (concurrent enrollment is permissible).

Same as: CHEMENG 470

CHEMENG 274. Environmental Microbiology I. 3 Units.

Basics of microbiology and biochemistry. The biochemical and biophysical principles of biochemical reactions, energetics, and mechanisms of energy conservation. Diversity of microbial catabolism, flow of organic matter in nature: the carbon cycle, and biogeochemical cycles. Bacterial physiology, phylogeny, and the ecology of microbes in soil and marine sediments, bacterial adhesion, and biofilm formation. Microbes in the degradation of pollutants. Prerequisites: CHEM 33, CHEM 121 (formerly CHEM 35), and BIOSCI 83, CHEMENG 181, or equivalents. Same as: BIO 273A, CEE 274A, CHEMENG 174

CHEMENG 277. Data Science and Machine Learning Approaches in Chemical and Materials Engineering. 3 Units.

Application of Data Science, Statistical Learning, and Machine Learning approaches to modern problems in Chemical and Materials Engineering. This course develops data science approaches, including their foundational mathematical and statistical basis, and applies these methods to data sets of limited size and precision. Methods for regression and clustering will be developed and applied, with an emphasis on validation and error quantification. Techniques that will be developed include linear and nonlinear regression, clustering and logistic regression, dimensionality reduction, unsupervised learning, neural networks, and hidden Markov models. These methods will be applied to a range of engineering problems, including conducting polymers, water purification membranes, battery materials, disease outcome prediction, genomic analysis, organic synthesis, and quality control in manufacturing. Prerequisites: CS 106A or permission from instructor. Same as: CHEMENG 177, MATSCI 166, MATSCI 176

CHEMENG 281. Biochemistry I. 4 Units.

Structure and function of major classes of biomolecules, including proteins, carbohydrates and lipids. Mechanistic analysis of properties of proteins including catalysis, signal transduction and membrane transport. Students will also learn to critically analyze data from the primary biochemical literature. Satisfies Central Menu Area 1 for Bio majors. Prerequisites: Chem 121 (formerly 35).

Same as: CHEM 181, CHEMENG 181

CHEMENG 283. Biochemistry II. 3 Units.

Focus on metabolic biochemistry: the study of chemical reactions that provide the cell with the energy and raw materials necessary for life. Topics include glycolysis, gluconeogenesis, the citric acid cycle, oxidative phosphorylation, photosynthesis, the pentose phosphate pathway, and the metabolism of glycogen, fatty acids, amino acids, and nucleotides as well as the macromolecular machines that synthesize RNA, DNA, and proteins. Medical relevance is emphasized throughout. Satisfies Central Menu Area 1 for Bio majors. Prerequisite: CHEM 181 or CHEM 141 or CHEMENG 181/281.

Same as: CHEM 183, CHEMENG 183

CHEMENG 296. Creating and Leading New Ventures in Engineering and Science-based Industries. 3 Units.

Open to seniors and graduate students interested in the creation of new ventures and entrepreneurship in engineering and science intensive industries such as chemical, energy, materials, bioengineering, environmental, clean-tech, pharmaceuticals, medical, and biotechnology. Exploration of the dynamics, complexity, and challenges that define creating new ventures, particularly in industries that require long development times, large investments, integration across a wide range of technical and non-technical disciplines, and the creation and protection of intellectual property. Covers business basics, opportunity viability, creating start-ups, entrepreneurial leadership, and entrepreneurship as a career. Teaching methods include lectures, case studies, guest speakers, and individual and team projects.

Same as: CHEM 196, CHEM 296, CHEMENG 196

CHEMENG 299. Graduate Practical Training. 1 Unit.

Only for graduate students majoring in Chemical Engineering. Students obtain employment in a relevant industrial or research activity to enhance their professional experience. Students submit a concise report detailing work activities, problems worked on, and key results. May be repeated for credit up to 3 units. Prerequisite: qualified offer of employment and consent of department. Prior approval by the Chemical Engineering Department is required; you must contact the Chemical Engineering Department's Student Services staff for instructions before being granted permission to enroll.

CHEMENG 300. Applied Mathematics in the Chemical and Biological Sciences. 3 Units.

Mathematical solution methods via applied problems including chemical reaction sequences, mass and heat transfer in chemical reactors, quantum mechanics, fluid mechanics of reacting systems, and chromatography. Topics include generalized vector space theory, linear operator theory with eigenvalue methods, phase plane methods, perturbation theory (regular and singular), solution of parabolic and elliptic partial differential equations, and transform methods (Laplace and Fourier). Prerequisites: CME 102/ENGR 155A and CME 104/ENGR 155B, or equivalents.

Same as: CME 330

CHEMENG 310. Microhydrodynamics. 3 Units.

Transport phenomena on small-length scales appropriate to applications in microfluidics, complex fluids, and biology. The basic equations of mass, momentum, and energy, derived for incompressible fluids and simplified to the slow-flow limit. Topics: solution techniques utilizing expansions of harmonic and Green's functions; singularity solutions; flows involving rigid particles and fluid droplets; applications to suspensions; lubrication theory for flows in confined geometries; slender body theory; and capillarity and wetting. Prerequisites: 120A,B, 300, or equivalents.

Same as: ME 451D

CHEMENG 320. Chemical Kinetics and Reaction Engineering. 3 Units.

Theoretical and experimental tools useful in understanding and manipulating reactions mediated by small-molecules and biological catalysts. Theoretical: first classical chemical kinetics and transition state theory; then RRKM theory and Monte Carlo simulations. Experimental approaches include practical application of modern spectroscopic techniques, stopped-flow measurements, temperature-jump experiments, and single-molecule approaches to chemical and biological systems. Both theory and application are framed with regard to systems of particular interest, including industrially relevant enzymes, organometallic catalysts, heterogeneous catalysis, electron transfer reactions, and chemical kinetics within living cells.

CHEMENG 340. Molecular Thermodynamics. 3 Units.

Classical thermodynamics and quantum mechanics. Development of statistical thermodynamics to address the collective behavior of molecules. Establishment of theories for gas, liquid, and solid phases, including phase transitions and critical behavior. Applications include electrolytes, ion channels, surface adsorption, ligand binding to proteins, hydrogen bonding in water, hydrophobicity, polymers, and proteins.

CHEMENG 345. Fundamentals and Applications of Spectroscopy. 3 Units.

Theoretical basis and experimental aspects of atomic and molecular spectroscopy, including spectroscopic transitions, transition probabilities, and selection rules. Applications of rotational, vibrational, and electronic spectroscopies emphasize the use of spectroscopy in modern research. Specific topics include but are not limited to microwave spectroscopy, infrared spectroscopy and Raman scattering, and photoelectron and fluorescence spectroscopies. Prerequisites: CME 104 or an equivalent intro to partial differential equations; CHEMENG 110A or CHEM 171 or an equivalent intro to physical chemistry.

Same as: PHOTON 345

CHEMENG 355. Advanced Biochemical Engineering. 3 Units.

Combines biological knowledge and methods with quantitative engineering principles. Quantitative review of biochemistry and metabolism; recombinant DNA technology and synthetic biology (metabolic engineering). The production of protein pharmaceuticals as a paradigm for the application of chemical engineering principles to advanced process development within the framework of current business and regulatory requirements. Prerequisite: CHEMENG 181 (formerly 188) or BIOSCI 41, or equivalent.

Same as: BIOE 355

CHEMENG 399. Graduate Research Rotation in Chemical Engineering. 1 Unit.

Introduction to graduate level laboratory and theoretical work. Performance in this course comprises part of the mandatory evaluation for pre-candidacy standing and suitability to continue in the chemical engineering Ph.D. program.

CHEMENG 420. Growth and Form. 3 Units.

Advanced topics course examining the role of physical forces in shaping living cells, tissues, and organs, making use of D'Arcy Thompson's classic text *On Growth and Form*. The course begins with a review of relevant physical principles drawn from statistical physics, polymer theory, rheology and materials science. We then examine current knowledge of cellular mechanotransduction pathways, the roles of physical forces in guiding embryonic development, and the contribution of aberrant cellular response to mechanical cues in heart disease and cancer. The course concludes by examining current frontiers in stem cell biology and tissue engineering.

CHEMENG 424. Structure and Reactivity of Solid Surfaces. 3 Units.

The structure of solid surfaces including experimental methods for determining the structure of single crystal surfaces. The adsorption of molecules on these surfaces including the thermodynamics of adsorption processes, surface diffusion, and surface reactions. Molecular structure of adsorbates. Current topics in surface structure and reactivity, including systems for heterogeneous catalysis and electronic materials.

CHEMENG 432. Electrochemical Energy Conversion. 3 Units.

Electrochemistry is playing an increasingly important role in renewable energy. This course aims to cover the fundamentals of electrochemistry, and then build on that knowledge to cover applications of electrochemistry in energy conversion. Topics to be covered include fuel cells, solar water-splitting, CO₂ conversion to fuels and chemicals, batteries, redox flow cells, and supercapacitors. Prerequisites: CHEM 31AB or 31 X, CHEM 33, CHEM 171, CHEM 175 or CHEMENG 170, or equivalents. Recommended: CHEM 173.

CHEMENG 442. Suspension Mechanics. 3-4 Units.

The course will begin with a brief recap of low-Reynolds number hydrodynamics and the analytical foundations for the study of pair-level particle interactions in a Newtonian solvent. Extension to many-body interactions will be covered in detail, with an introductory overview of computational methods. Brownian motion, thermodynamic forces, and other interparticle forces will be discussed, and various approaches for theoretical modeling will be covered, including Fokker-Planck / Smoluchowski analysis and Langevin analysis. Theoretical and computational modeling of material properties via averaging techniques will be studied, in the context of micromechanical and continuum models. Landmark results in the microrheology and rheology of complex fluids will be covered, including sedimentation, non-Newtonian rheology (including shear thinning and thickening; viscoelasticity and memory behaviors; yield-stress behavior; glassy aging; diffusion; normal stress differences).

CHEMENG 443. Principles and practice of heterogeneous catalysis. 3 Units.

Principles and practical aspects of heterogeneous catalysis. Preparation of catalytic solids. Techniques for the structural characterization of catalysts, including in-situ and operando. Best practices in both structural and catalytic characterization. Kinetic experiments for the characterization of catalytic activity of materials and the determination of active sites. Examples of industrial catalytic processes utilizing heterogeneous catalysts. Perspectives on the role of heterogeneous catalysis in energy and environmental challenges. Pre-Reqs: UG physical chemistry (171), thermodynamics (110) and kinetics (130) or equivalents.

CHEMENG 444. Electronic Structure Theory and Applications to Chemical Kinetics. 3 Units.

Fundamentals of electronic structure theory to describe materials properties and chemical reactivity. nLearning objectives: Understand the basis for modern electronic structure calculations, understand the relationship between electronic structure, materials properties, and chemical kinetics, be able to read the current literature, be able to do own calculations. nImportant components of the lectures: An overview of quantum chemical methods, introduction to methods for periodic systems, density functional theory and current approximations to describe exchange and correlation effects, methods to describe excited states, transition state theory and methods to calculate partition functions. nThe Lab: Learning to do DFT calculations.

CHEMENG 450. Advances in Biotechnology. 3 Units.

Overview of cutting edge advances in biotechnology with a focus on therapeutic and health-related topics. Academic and industrial speakers from a range of areas including protein engineering, immuno-oncology, DNA sequencing, the microbiome, pharmacogenomics, industrial enzymes, synthetic biology, and more. Course is designed for students interested in pursuing a career in the biotech industry. Same as: BIOE 450

CHEMENG 454. Synthetic Biology and Metabolic Engineering. 3 Units.

Principles for the design and optimization of new biological systems. Development of new enzymes, metabolic pathways, other metabolic systems, and communication systems among organisms. Example applications include the production of central metabolites, amino acids, pharmaceutical proteins, and isoprenoids. Economic challenges and quantitative assessment of metabolic performance. Pre- or corequisite: CHEMENG 355 or equivalent. Same as: BIOE 454

CHEMENG 456. Microbial Bioenergy Systems. 3 Units.

Introduction to microbial metabolic pathways and to the pathway logic with a special focus on microbial bioenergy systems. The first part of the course emphasizes the metabolic and biochemical principles of pathways, whereas the second part is more specifically directed toward using this knowledge to understand existing systems and to design innovative microbial bioenergy systems for biofuel, biorefinery, and environmental applications. There also is an emphasis on the implications of rerouting of energy and reducing equivalents for the fitness and ecology of the organism. Prerequisites: CHEMENG 174 or 181 and organic chemistry, or equivalents. Same as: BIO 273B, CEE 274B

CHEMENG 459. Frontiers in Interdisciplinary Biosciences. 1 Unit.

Students register through their affiliated department; otherwise register for CHEMENG 459. For specialists and non-specialists. Sponsored by the Stanford BioX Program. Three seminars per quarter address scientific and technical themes related to interdisciplinary approaches in bioengineering, medicine, and the chemical, physical, and biological sciences. Leading investigators from Stanford and the world present breakthroughs and endeavors that cut across core disciplines. Pre-seminars introduce basic concepts and background for non-experts. Registered students attend all pre-seminars; others welcome. See <http://biox.stanford.edu/courses/459.html>. Recommended: basic mathematics, biology, chemistry, and physics. Same as: BIO 459, BIOE 459, CHEM 459, PSYCH 459

CHEMENG 460. Interfacial Engineering of Soft Matter. 3 Units.

Interfacial engineering is a culmination of a century of interdisciplinary science and engineering. The foundation is provided by the thermodynamics of surface tension, surface chemistry and adsorption, which govern the properties of catalysts, colloids and surfactants. Microminiaturization of soft and hard materials and the growth of nanotechnology have led to dramatic increases in the surface-to-volume ratio. Knowledge of the principles of interfacial engineering can be used in the application domains of microelectronics chips and packaging, polymer composites, advanced ceramics, biomedical implants and bioanalytical devices. This course will cover the fundamentals of interface physics and chemistry, with an emphasis on soft matter, including phospholipids, proteins and synthetic polymers at interfaces. Specific topics will include intermolecular forces and potentials; solvation, structural and hydration forces; particle-particle interactions; interfacial thermodynamics; Poisson-Boltzmann theory of the diffuse electric double layer; electrokinetic phenomena; colloidal aggregation; and molecular assemblies.

CHEMENG 462. Complex Fluids and Non-Newtonian Flows. 3 Units.

Definition of a complex liquid and microrheology. Division of complex fluids into suspensions, solutions, and melts. Suspensions as colloidal and non-colloidal. Extra stress and relation to the stresslet. Suspension rheology including Brownian and non-Brownian fibers. Microhydrodynamics and the Fokker-Planck equation. Linear viscoelasticity and the weak flow limit. Polymer solutions including single mode (dumbbell) and multimode models. Nonlinear viscoelasticity. Intermolecular effects in nondilute solutions and melts and the concept of reptation. Prerequisites: low Reynolds number hydrodynamics or consent of instructor. Same as: ME 455

CHEMENG 464. Polymer Chemistry. 3 Units.

Polymer material design, synthesis, characterization, and application. Topics include organic and kinetic aspects of polymerization, polymer characterization techniques, and structure and properties of bulk polymers for commercial applications and emerging technologies.

CHEMENG 466. Polymer Physics. 3 Units.

Concepts and applications in the equilibrium and dynamic behavior of complex fluids. Topics include solution thermodynamics, scaling concepts, semiflexibility, characterization of polymer size (light scattering, osmotic pressure, size-exclusion chromatography, intrinsic viscosity), viscoelasticity, rheological measurements, polyelectrolytes, liquid crystals, biopolymers, and gels.

CHEMENG 469. Solid Structure and Properties of Polymers. 3 Units.

Fundamental structure-properties relationships of solid polymers in bulk and thin films. Topics include chain conformations in bulk amorphous polymers, glass transition, crystallization, semi-crystalline morphology, liquid crystalline order, polymer blends, block copolymers, polymer networks/gels, polymers of high current interest, and experimental methods of characterizing polymer structure.

CHEMENG 470. Mechanics of Soft Matter: Rheology. 3 Units.

Soft matter comes in many forms and includes polymeric materials, suspensions, emulsions, foams, gels, and living tissue. These materials are characterized by being easily deformed and possessing internal relaxation time spectra. They are viscoelastic with responses that are intermediate between purely viscous liquids and perfectly elastic solids. This course provides an introduction to the subject of rheology, which concerns the deformation and flow of complex liquids and solids. Rheological testing is aimed at determining the relationships between the applied stresses in these materials and the resulting deformations. These are characterized by material functions, such as viscosity (shear and extensional), moduli, and compliances. These functions reflect the microstructure of the material being tested and microstructural models of polymers (single chain theories and reptation-based models), suspensions, emulsions, and foams will be presented. Experimental methods to measure materials subjected to both shearing and elongational deformations will be described. Many soft matter systems are influenced by interfacial phenomena (foams, emulsions, thin films in the human body) and interfacial rheological techniques will be discussed. Advanced undergraduates register for 270; graduates register for 470. Prerequisites: ChE 120A or its equivalent (concurrent enrollment is permissible).

Same as: CHEMENG 270

CHEMENG 482. The Startup Garage: Design. 4 Units.

(Same as STRAMGT 356) The Startup Garage is an experiential lab course that focuses on the design, testing and launch of a new venture. Multidisciplinary student teams work through an iterative process of understanding user needs, creating a point of view statement, ideating and prototyping new product and services and their business models, and communicating the user need, product, service and business models to end-users, partners, and investors. In the autumn quarter, teams will: identify and validate a compelling user need and develop very preliminary prototypes for a new product or service and business models. Students form teams, conduct field work and iterate on the combination of business model – product – market. Teams will present their first prototypes (business model - product - market) at the end of the quarter to a panel of entrepreneurs, venture capitalists, angel investors and faculty.

Same as: SOMGEN 282

CHEMENG 484. The Startup Garage: Testing and Launch. 4 Units.

This is the second quarter of the two-quarter series. In this quarter, student teams expand the field work they started in the fall quarter. They get out of the building to talk to potential customers, partners, distributors, and investors to test and refine their business model, product/service and market. This quarter the teams will be expected to develop and test a minimally viable product, iterate, and focus on validated lessons on: the market opportunity, user need and behavior, user interactions with the product or service, business unit economics, sale and distribution models, partnerships, value proposition, and funding strategies. Teams will interact with customers, partners, distributors, investors and mentors with the end goal of developing and delivering a funding pitch to a panel of entrepreneurs, venture capitalists, angel investors and faculty.

Same as: SOMGEN 284

CHEMENG 500. Special Topics in Protein Biotechnology. 1 Unit.

Recent developments and current research. May be repeated for credit. Prerequisite: graduate standing and consent of instructor.

CHEMENG 501. Special Topics in Semiconductor Processing. 1 Unit.

Recent developments and current research. May be repeated for credit. Prerequisite: graduate standing and consent of instructor.

CHEMENG 503. Special Topics in Biocatalysis. 1 Unit.

Recent developments and current research. May be repeated for credit. Prerequisite: graduate standing and consent of instructor.

CHEMENG 505. Special Topics in Microrheology. 1 Unit.

Recent developments and current research. May be repeated for credit. Prerequisite: graduate standing and consent of instructor.

CHEMENG 507. Special Topics in Polymer Physics and Molecular Assemblies. 1 Unit.

Recent developments and current research. May be repeated for credit. Prerequisite: graduate standing and consent of instructor.

CHEMENG 510. Special Topics in Transport Mechanics. 1 Unit.

Recent developments and current research. May be repeated for credit. Prerequisite: graduate standing and consent of instructor.

CHEMENG 513. Special Topics in Functional Organic Materials for Electronic and Optical Devices. 1 Unit.

Recent developments and current research. May be repeated for credit. Prerequisite: graduate standing and consent of instructor.

CHEMENG 514. Special Topics in Biopolymer Physics. 1 Unit.

Recent developments and current research. May be repeated for credit. Prerequisite: graduate standing and consent of instructor.

CHEMENG 515. Special Topics in Molecular and Systems Biology. 1 Unit.

Recent developments and current research. May be repeated for credit. Prerequisite: graduate standing and consent of instructor.

CHEMENG 516. Special Topics in Energy and Catalysis. 1 Unit.

Recent developments and current research. May be repeated for credit. Prerequisite: graduate standing and consent of instructor.

CHEMENG 517. Special Topics in Microbial Physiology and Metabolism. 1 Unit.

Recent developments and current research. May be repeated for credit. Prerequisite: graduate standing and consent of instructor.

CHEMENG 518. Special Topics in Advanced Biophysics and Protein Design. 1 Unit.

Recent developments and current research. May be repeated for credit. Prerequisite: graduate standing and consent of instructor.

CHEMENG 519. Special Topics in Interface Science and Catalysis. 1 Unit.

Recent developments and current research. May be repeated for credit. Prerequisite: graduate standing and consent of instructor.

CHEMENG 520. Special Topics in Biological Chemistry. 1 Unit.

Recent developments and current research. May be repeated for credit. Prerequisite: graduate standing and consent of instructor.

CHEMENG 521. Special Topics in Nanostructured Materials for Energy and the Environment. 1 Unit.

Recent developments and current research. May be repeated for credit.
Prerequisite: graduate standing and consent of instructor.

CHEMENG 522. Special Topics in Soft Matter and Molecular Physics. 1 Unit.

Recent developments and current research. May be repeated for credit.
Prerequisite: graduate standing and consent of instructor.

CHEMENG 523. Special Topics in Suspension Dynamics. 1 Unit.

Recent developments and current research. May be repeated for credit.
Prerequisite: graduate standing and consent of instructor.

CHEMENG 524. Special Topics in Electrochemistry and Water Treatment. 1 Unit.

Recent developments and current research. May be repeated for credit.
Prerequisite: graduate standing and consent of instructor.

CHEMENG 600. Graduate Research in Chemical Engineering. 1-12 Unit.

Laboratory and theoretical work leading to partial fulfillment of requirements for an advanced degree. Course may be repeated for credit.

CHEMENG 699. Colloquium. 1 Unit.

Weekly lectures by experts from academia and industry in the field of chemical engineering. Course may be repeated for credit.

CHEMENG 801. TGR Project. 0 Units.**CHEMENG 802. TGR Dissertation. 0 Units.**