DEPARTMENT OF CHEMICAL ENGINEERING

Chemical engineering encompasses the translation of molecular information into discovery of new products and processes. It involves molecular transformations—chemical, physical, and biological—with multi-scale description from the submolecular to the macroscopic, and the analysis and synthesis of such systems. The chemical engineer is well prepared for a rewarding career in a strikingly diverse array of industries and professional arenas. Whether these industries are at the cutting edge—e.g., nanotechnology or biotechnology—or traditional, they depend on chemical engineers to make their products and processes a reality. The effectiveness of chemical engineers in such a broad range of areas begins with foundational knowledge in chemistry, biology, physics, and mathematics. From this foundation, chemical engineers develop core expertise in engineering thermodynamics, transport processes, and chemical kinetics, creating a powerful and widely applicable combination of molecular knowledge and engineering problem solving. To cope with complex, real-world problems, chemical engineers develop strong synthetic and analytic skills. Through creative application of these chemical engineering principles, chemical engineers create innovative solutions to important industrial and societal problems in areas such as development of clean energy sources, advancement of life sciences, production of pharmaceuticals, sustainable systems and responsible environmental stewardship, and discovery and production of new materials.

The Department of Chemical Engineering at MIT offers four undergraduate programs. Course 10 leads to the Bachelor of Science in Chemical Engineering through a curriculum that prepares the graduate for a wide range of career pursuits. Course 10-B leads to the Bachelor of Science in Chemical-Biological Engineering, which includes the basic engineering core from the Course 10 degree and adds material in basic and applied biology. Course 10-ENG leads to the Bachelor of Science in Engineering, a more flexible curriculum that supplements a chemical engineering foundation with an area of technical specialization. Course 10-C leads to the Bachelor of Science without specification; this non-accredited degree requires fewer chemical engineering subjects. Undergraduates have access to graduate-level subjects in their upper-level years. Undergraduate students are also encouraged to participate in research through the Undergraduate Research Opportunities Program (UROP) (*http://web.mit.edu/urop*).

The department offers a broad selection of graduate subjects and research topics leading to advanced degrees in chemical engineering. Multidisciplinary approaches are highly valued, leading to strong ties with other MIT departments. In addition, the department maintains alliances, arrangements, and connections with institutions and industries worldwide. Areas for specialization include, but are not limited to: biochemical engineering, biomedical engineering, biotechnology, chemical catalysis, chemical process development, environmental engineering, fuels and energy, polymer chemistry, surface and colloid chemistry, systems engineering, and transport processes. Additional information may be found under Graduate Education (*https://catalog.mit.edu/mit/graduate-education*) and on the department's website (*http://web.mit.edu/cheme*).

The School of Chemical Engineering Practice, leading to five-year bachelor's and master's degrees, involves one term of work under the direction of an Institute staff member resident at Practice School sites. This program provides students with a unique opportunity to apply basic professional principles to the solution of practical industrial problems.

Undergraduate Study

The undergraduate curriculum in chemical engineering provides basic studies in physics, biology, and mathematics, advanced subjects in chemistry or biology, and a strong core of chemical engineering. The four-year undergraduate programs provide students with the fundamentals of the discipline and allow some room for focus in subdisciplines or subjects that strengthen their preparation for advanced work.

In addition to science and engineering, students take an integrated sequence of subjects in the humanities and social sciences. Specific subject selection allows students to meet individual areas of interest. The curriculum provides a sound preparation for jobs in industry or government, and for graduate work in chemical engineering.

Chemical engineering also provides excellent preparation for careers in medicine and related fields of health science and technology. The department's strong emphasis on chemistry and biology provides excellent preparation for medical school. Students interested in medical school work with their faculty and premedical advisor to create the best program. A minor in biomedical engineering is also available.

Bachelor of Science in Chemical Engineering (Course 10)

The Bachelor of Science in Chemical Engineering degree program (*https://catalog.mit.edu/degree-charts/chemical-engineering-course-10*) is intended for the student who seeks a broad education in the application of chemical engineering to a variety of specific areas, including energy and the environment, nanotechnology, polymers and colloids, surface science, catalysis and reaction engineering, systems and process design, and biotechnology. The degree requirements include the core chemical engineering subjects with a chemistry emphasis, and the opportunity to add subjects in any of these application areas.

Course 10 is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET) (*http://www.abet.org*) as a chemical engineering degree.

Bachelor of Science in Chemical-Biological Engineering (Course 10-B)

The Bachelor of Science in Chemical-Biological Engineering degree program (*https://catalog.mit.edu/degree-charts/chemical-biological-engineering-course-10-b*) is intended for the student who is specifically interested in the application of chemical engineering in the areas of biochemical and biomedical technologies. The degree requirements include core chemical engineering subjects and additional subjects in biological sciences and applied biology. This degree is excellent preparation for students also considering the biomedical engineering minor or medical school.

Course 10-B is accredited by the Engineering Accreditation Commission of ABET as a chemical and biological engineering degree.

Students who decide early to major in either Course 10 or Course 10-B are encouraged to take subjects such as 5.111/5.112 Principles of Chemical Science, 5.12 Organic Chemistry I, and 7.01x Introductory Biology in their first year. Then 5.601 Thermodynamics I, 18.03 Differential Equations, 10.10 Introduction to Chemical Engineering, 10.213 Chemical and Biological Engineering Thermodynamics, and 10.301 Fluid Mechanics may be taken in the sophomore year. The student is then well positioned for more in-depth and specialized subjects in the third and fourth years.

Some students may wish to defer choice of a major field or exercise maximum freedom during the first two years. If the Restricted Electives in Science and Technology (REST) Requirement subjects chosen in the second year include 18.03 Differential Equations and two subjects in the fields of fluid mechanics, thermodynamics, chemistry, biology, or chemical engineering, students can generally complete the requirements for a degree in chemical engineering in two more years. Students are advised to discuss their proposed program with a Course 10 faculty advisor as soon as they become interested in a degree in chemical engineering. Faculty advisors are assigned to students as soon as they declare their major and then work with the students through graduation. Further information may be obtained from Dr. Barry S. Johnston.

Additional information is available on the Chemical Engineering Department website (*http://web.mit.edu/cheme*). Undergraduates are encouraged to take part in the research activities of the department through the Undergraduate Research Opportunities Program (UROP) (*http://uaap.mit.edu/research-exploration/urop*).

Bachelor of Science as Recommended by the Department of Chemical Engineering (Course 10-C)

The curriculum for the Bachelor of Science as Recommended by the Department of Chemical Engineering (Course 10-C) (*https://catalog.mit.edu/degree-charts/chemical-engineering-course-10-c*) involves basic subjects in chemistry and chemical engineering. Instead of continuing in depth in these areas, students can add breadth by study in another field, such as another engineering discipline, biology, biomedical engineering, economics, or management. Course 10-C is attractive to students who wish to specialize in an area such as those cited above while simultaneously gaining a broad exposure to the chemical engineering approach to solving problems.

Students planning to follow this curriculum should discuss their interests with their faculty advisor in the department at the time they decide to enter the Course 10-C program, and submit to Dr. Barry S. Johnston in the department's Undergraduate Office a statement of goals and a coherent program of subjects no later than spring term of junior year. Please direct questions about this program to Dr. Johnston.

Bachelor of Science in Engineering (Course 10-ENG)

The Bachelor Science in Engineering (10-ENG) degree program (*https://catalog.mit.edu/degree-charts/engineering-chemical-engineering-course-10-eng*) is designed to offer flexibility within the context of chemical engineering while ensuring significant engineering content, and is a complement to our chemical engineering degree programs 10 and 10-B. The degree is designed to enable students to pursue a deeper level of understanding in a specific interdisciplinary field that is relevant to the chemical engineering core discipline. The degree requirements include all of the core chemical engineering coursework, plus a chosen set of three foundational concept subjects and four subjects with engineering content that make up a comprehensive concentration specific to the interdisciplinary area selected by the student. The concentrations have been selected by the Department of Chemical Engineering to represent new and developing cross-disciplinary areas that benefit from a strong foundation in engineering within the chemical engineering context. Details of the concentrations are available from the Chemical Engineering Student Office and the department's website (*https://cheme.mit.edu/academics/undergraduate-students/undergraduate-programs/course-10-eng*).

The foundational concept component of the flexible engineering degree consist of basic science and engineering subjects that help lay the groundwork for the chosen concentration. Three subjects must be selected from a list of potential topics. One of the foundational concept subjects must be a chemical engineering CI-M subject, and one must be a laboratory subject that satisfies the Institute Laboratory Requirement. The subjects should be selected with the assistance of a 10-ENG degree advisor from the Chemical Engineering Department so as to be consistent with the degree requirements of the program and the General Institute Requirements. Several of these subjects can satisfy the program's CI-M requirement.

The flexible engineering concentration consists of four subjects that are selected by the student from a suggested subject list provided for each 10-ENG concentration; the student also may propose subjects that fit the theme of the chosen concentration. These lists are included in the concentration descriptions provided on the department's website and at the Chemical Engineering Student

Office. Students work with their 10-ENG advisors to propose a 10-ENG degree program, which must then be approved by the Chemical Engineering Undergraduate Committee.

The flexible engineering degree major capstone experience consists of 12 units and/or a senior-level project. Alternatively, the student may choose to complete a senior thesis in a topic area relevant to the concentration. Senior-level projects or senior thesis projects are specifically designed to integrate engineering principles into specific applications or problems and are not standard UROP projects; such projects require the preliminary approval of the department's undergraduate officer.

Course 10-ENG is accredited by the Engineering Accreditation Commission of ABET as an engineering degree.

Five-Year Programs and Joint Programs

In addition to offering separate programs leading to the Bachelor of Science and Master of Science in Chemical Engineering, the department offers a program leading to the simultaneous award of both degrees at the end of five years. A detailed description of this program is available from the Graduate Student Office. Students in the five-year program normally enroll in the School of Chemical Engineering Practice.

For chemical engineering students interested in nuclear applications, the Department of Chemical Engineering and the Department of Nuclear Engineering offer a five-year program leading to the joint Bachelor of Science in Chemical Engineering and Master of Science in Nuclear Engineering. Such programs are approved on an individual basis between the registration officers of the two departments.

Inquiries

Additional information concerning undergraduate academic and research programs may be obtained by writing to Dr. Barry S. Johnston (*bsjohnst@mit.edu*), undergraduate officer, Department of Chemical Engineering, Room 66-368, 617-258-7141, fax 617-258-0546. For information regarding admissions and financial aid, contact the Admissions Office, Room 3-108, 617-253-4791.

Graduate Study

Graduate study provides both rigorous training in the fundamental core discipline of chemical engineering and the opportunity to focus on specific subdisciplines. In addition to completing the four core subject requirements in thermodynamics, reaction engineering, numerical methods, and transport phenomena, students select a research advisor and area for specialization, some of which are discussed below.

Thermodynamics and Molecular Computation. Thermodynamics is a cornerstone of chemical engineering. Processes as diverse as chemical production, bioreaction, creation of advanced materials, protein separation, and environmental treatment are governed by thermodynamics. The classical concepts of equilibrium, reversibility, energy, and entropy are basic to the analysis and design of these processes. The extension of classical thermodynamics to molecular scales by use of statistical mechanics has made molecular simulation an increasingly valuable tool for the chemical engineer. Prediction of macroscopic behavior from molecular computations is becoming ever more feasible. This venerable field continues to yield fruitful areas of inquiry.

Opportunities in the department for graduate study in this field include predicting properties of materials and polymers from molecular structure, applying quantum mechanics to catalyst design, supercritical fluid processing, the behavior of complex fluids with environmental and biomedical applications, phase equilibrium with simple and complex molecular species, immunology, protein stabilization, nucleation and crystallization of polymer and pharmaceuticals, and many other areas of classical and statistical thermodynamics.

Transport Processes. A fluid deforming and flowing as forces are imposed on it, its temperature varying as heat is transferred through it, the interdiffusion of its distinct molecular species—these are examples of the processes of transport. These transport processes govern the rates at which velocity, temperature, and composition vary in a fluid; chemical engineers study transport to be able to describe, predict, and manage these changes. Research includes experimental testing and analytical and computational modeling; its applications range among an enormous variety of mechanical, chemical, and biological processes.

Current work includes the study of polymer molecular theory and polymer processing, transport and separations in magnetorheological fluids, membrane separations, diffusion in complex fluids, defect formation and evolution in near-crystalline materials, microfluidics, fluid instability, transport in living tissue, numerical solution of field equations, and many other areas of transport phenomena.

Catalysis and Chemical Reaction Engineering. A simple chemical reaction—the rearrangement of electrons and bonding partners—occurs between two small molecules. From understanding the kinetics of the reaction, and the equilibrium extent to which it can proceed, come applications: the network of reactions during combustion, the chain reactions that form polymers, the multiple steps in the synthesis of a complex pharmaceutical molecule, the specialized reactions of proteins and metabolism. Chemical kinetics is the chemical engineer's tool for understanding chemical change.

A catalyst influences the reaction rate. Catalysts are sought for increasing production, improving the reaction conditions, and emphasizing a desired product among several possibilities. The challenge is to design the catalyst, to increase its effectiveness and stability, and to create methods to manufacture it.

A chemical reactor should produce a desired product reliably, safely, and economically. In designing a reactor, the chemical engineer must consider how the chemical kinetics, often modified by catalysis, interacts with the transport phenomena in flowing materials. New microreactor designs are expanding the concept of what a reactor may do, how reactions may be conducted, and what is required to scale a process from laboratory to production.

Research is being conducted in the department at the forefront of catalyst design, complex chemical synthesis, bioreactor design, surface- and gas-phase chemistry, miniaturization of reactors, mathematical modeling of chemical reaction networks, and many other areas of chemical reaction engineering. Applications include the manufacturing of chemicals, refining of fuels for transportation and power, and microreactors for highly reactive or potentially hazardous materials.

Polymers. Wondrous materials found in nature and now synthesized in enormous quantity and variety, polymers find an ever-increasing use in manufactured products. Polymers are versatile because their properties are so wide-ranging, as is evident even in the conceptually simple polymers made from a single molecular species. The versatility becomes more profound in the copolymers made from multiple precursors, and the polymers compounded with filler materials. Research in polymers encompasses the chemical reactions of their formation, methods of processing them into products, means of modifying their physical properties, and the relationship between the properties and the underlying molecular- and solid-phase structure.

Graduate research opportunities in the department include studies of polymerization kinetics, non-Newtonian rheology, polymer thin films and interfaces, block copolymers, liquid crystalline polymers, nanocomposites and nanofibers, self-assembly and patterning, and many other areas of polymer science and engineering. In addition to a program in graduate study in polymers within the department, the interdisciplinary Program in Polymers and Soft Matter (PPSM) provides a community for researchers in the polymer field and offers a program of study that focuses on the interdisciplinary nature of polymer science and engineering.

Materials. The inorganic compounds found in nature are the basis for new materials made by modifying molecular composition (such as purifying silicon and doping it with selected impurities) and structure (such as control of pore and grain size). These materials have electronic, mechanical, and optical properties that support a variety of novel technologies. Other materials are applied as coatings—thin films that create a functional surface. Still other materials have biological applications, such as diagnostic sensors that are compatible with living tissue, barriers that control the release of pharmaceutical molecules, and scaffolds for tissue repair. A new generation of biomaterials is being derived from biological molecules. Research in materials is wide-ranging and highly interdisciplinary, both fundamental and applied. In the department, materials research includes studies in plasma etching, thin-film chemical vapor deposition, crystal growth, nano-crystalline structure, molecular simulation, scaffolds for bone and soft tissue regeneration, biocompatible polymers, and many other areas of materials engineering.

Surfaces and Nanostructures. In many arrangements of matter, the interfaces between phases—more than their bulk compositions —are critical to the material structure and behavior. The surfaces of solids offer a platform for functional coating; coatings may be deposited from vapor, applied as a volatile liquid, or assembled from solution onto the solid, in a pattern determined by the molecular properties. This self-assembly tendency may be exploited to arrange desired patterns that have operational properties. Interfacial effects are also responsible for stable dispersions of immiscible phases, leading to fluids with complex microstructure. Other structured fluids arise from large molecules whose orientation in the solvent is constrained by molecular size and properties. In solids, tight control of pore size, grain size, chemical composition, and crystal structure offer a striking range of catalytic, mechanical, and electromagnetic properties. The understanding of gas-solid kinetics is crucial to the study of heterogeneous catalysis and integrated circuit fabrication. Structure is the basis for function, and by manipulating tiny length scales, the resulting nanostructure makes available new capabilities, and thus new technologies and products. Graduate study in surfaces and nanostructures may include studies of colloids, emulsions, surfactants, and other structured fluids with biological, medical, or environmental applications. It also encompasses thin films, liquid crystals, sol-gel processing, control of pharmaceutical morphology, nanostructured materials, carbon nanotubes, surface chemistry, surface patterning, and many other areas of nanotechnology and surface science.

Biological Engineering. Chemical engineering thermodynamics, transport, and chemical kinetics, so useful for manufacturing processes, are fruitful tools for exploring biological systems as well. Biological engineering research may be directed at molecular-level processes, the cell, tissues, the organism, and large-scale manufacturing in biotech processes. It may be applied to producing specialized proteins, genetic modification of cells, transport of nutrients and wastes in tissue, therapeutic methods of drug delivery, tissue repair and generation, purification of product molecules, and control strategies for complex bioproduction plants. Its methods include analytical chemistry and biochemistry techniques, bioinformatic processing of data, and computational solution of chemical reaction and transport models. Biological engineering is an extraordinarily rich area for chemical engineers, and its consequences—theoretical, medical, commercial—will be far-reaching.

Opportunities in the department for graduate study in biological engineering include manipulation and purification of proteins and other biomolecules, research into metabolic processes, tissue regeneration, gene regulation, bioprocesses, bioinformatics, drug delivery, and biomaterials, to name a few. Both experimental and computational methods are used, including statistical mechanics and systems theory. Chemical engineering faculty are also involved in the Center for Biomedical Engineering, created to enhance interdisciplinary research and education at the intersection of engineering, molecular and cell biology, and medicine. The Novartis-MIT Center for Continuous Manufacturing, another center of research activity involving chemical engineers, promises to revolutionize the chemical processing of pharmaceuticals.

Energy and Environmental Engineering. Making energy available to society requires finding and producing a range of fuels, improving the efficiency of energy use under the ultimate limits imposed by thermodynamics, and reducing the effects of these processes on the environment. The widespread use of fossil fuels increases the amount of carbon dioxide in the atmosphere, leading to concerns about global warming. Other sustainability indicators also suggest that we now need to transform our energy system to a more efficient, lower-carbon future. This transformation provides many opportunities for chemical engineers to evaluate and explore other energy supply options such as renewable energy from solar, biomass, and geothermal resources, nonconventional fuels from heavy oils, tar sands, natural gas hydrates, and oil shales. Developing technologies for transporting and storing thermal and electrical energy over a range of scales are also of interest.

Further environmental distress can result from manufacturing processes and society's use of the manufactured products. The traditional response of treating process wastes is still useful, but there is growing emphasis on designing new processes to produce less waste. This might be done by improving catalysts to decrease unwanted by-products, finding alternatives to volatile solvents, and developing more effective separation processes. Chemical engineers are at work in these areas, and in developing alternative energy sources and assessing the effects of pollutants on human health.

In the department, students will find expertise in combustion, chemical reaction networks, renewable energy and upgrading of nonconventional fuels, carbon dioxide capture and sequestration, water purification and catalytic treatment of pollutants, global air pollution modeling, design of novel energy conversion processes, energy supply chains, and many other areas of energy and environmental engineering. Faculty in the department are actively involved in the MIT Energy Initiative.

Systems Design and Simulation. From early in the development of chemical engineering, processes were represented as combinations of unit operations. This concept was useful in analyzing processes, as well as providing a library of building blocks for creating new processes. Process and product design are imaginative activities, an artful blend of intuition and analysis. Design is aided by mathematical tools that simulate the behavior of the process or product and seek optimum performance. Effective use of simulation and optimization tools allows unexpected pathways to be explored, dangerous operating regions to be identified, and transient and accident conditions to be tested. Process and product systems engineering brings it all together, placing the technical features of a process or product in the context of operations, economics, and business. The end result is improved economy, reliability, and safety. Methodologies for process and product modeling and simulation, computer-aided engineering, operations research, optimization theory and algorithms, process and product design strategy, treatment of uncertainty, multiscale systems engineering, and many other areas of systems engineering are being developed in the Department of Chemical Engineering. Such research leads to new prototypes for process systems, design of new molecules with desired properties, and processes with better operability, control, safety, and environmental performance.

School of Chemical Engineering Practice

Since 1916, the David H. Koch School of Chemical Engineering Practice has been a major feature of the graduate education in the department. In this unique program, students receive intensive instruction to broaden their education in the technical aspects of the profession, and also in communication skills and human relations, which are frequently decisive factors in the success of an engineering enterprise. The Practice School program stresses problem solving in an engineering internship format, where students undertake projects at industrial sites under the direct supervision of resident MIT faculty. Credit is granted for participation in the Practice School in lieu of preparing a master's thesis.

The operation of the Practice School is similar to that of a small consulting company. The resident staff work closely with the technical personnel of the host companies in identifying project assignments with significant educational merit, and with solutions that make important contributions to the operation of the company.

During Practice School, students work on three or four different projects. Groups and designated group leaders change from one project to another, giving every individual an opportunity to be a group leader at least once.

Students in the Practice School program are required to demonstrate proficiency, or take one graduate subject, in each of the following areas: thermodynamics, heat and mass transfer, applied process chemistry, kinetics and reactor design, systems engineering, and applied mathematics.

Master of Science in Chemical Engineering

Programs for the Master of Science in Chemical Engineering usually are arranged as a continuation of undergraduate professional training, but at a greater level of depth and maturity. The general requirements for a master's program are given in the section on Graduate Education (*https://catalog.mit.edu/mit/graduate-education*). To complete the requirement of at least 66 graduate subject units, together with an acceptable thesis, generally takes four terms.

Master of Science in Chemical Engineering Practice

The unit requirements for the Master of Science in Chemical Engineering Practice (Course 10-A) are the same as those for the

Master of Science in Chemical Engineering, except that 48 units of Practice School experience replace the master's thesis.

In some cases, Bachelor of Science graduates of this department can meet the requirements for the Master of Science in Chemical Engineering Practice (Course 10-A) in two terms. Beginning in September following graduation, students complete the required coursework at the Institute. The spring semester is spent at the Practice School field stations. Careful planning of the senior year schedule is important.

For students who have graduated in chemical engineering from other institutions, the usual program of study for the Master of Science in Chemical Engineering Practice involves two terms at the Institute followed by field station work in the Practice School. Graduates in chemistry from other institutions normally require an additional term.

Doctor of Science or Doctor of Philosophy

Doctoral candidates are required to pass a qualifying exam which contains two parts - a written and oral examination. The written qualifying exam consists of a thesis proposal document. The oral qualifying exam consists of the presentation of the thesis proposal to a faculty committee, including discussion and questions. The qualifying exam is usually completed within 16 months of starting residence as a graduate student. Completing a master's degree is not a prerequisite for entering the doctoral program or obtaining a doctoral degree.

The requirements for the doctoral degree include a program of advanced study, a minor program, a biology requirement, and a thesis. The program of advanced study and research is normally carried out in one of the fields of chemical engineering under the supervision of one or more faculty members in the Department of Chemical Engineering. A thesis committee of selected faculty monitors the doctoral program of each candidate.

Doctor of Philosophy in Chemical Engineering Practice

This degree program provides educational experience that combines advanced work in manufacturing, independent research, and management. The program is built on the outstanding research programs within the department, the unique resources of the David H. Koch School of Chemical Engineering Practice, and the world-class resources of the Sloan School of Management. Students are prepared for a rapid launch into positions of leadership in industry and provided with a foundation for completion of an MBA degree.

The program consists of three major parts: the first year is devoted to coursework and the Practice School, the two middle years are devoted to research, and the final year is completed in the Sloan School of Management. In addition, an integrative project combines the research and management portions of the program.

Students in the PhD in Chemical Engineering Practice (PhDCEP) program must pass the department's written and oral examinations. The progress of their research is monitored by a faculty committee, and the final thesis document is defended in a public forum. The normal completion time should be four calendar years for the PhDCEP program.

Interdisciplinary Programs

Computational Science and Engineering Doctoral Program

The Doctoral Program in Computational Science and Engineering (CSE PhD) (*https://cse.mit.edu/programs/phd*) allows students to specialize in a computation-related field of their choice through focused coursework and a doctoral thesis through a number of participating host departments. The CSE PhD program is administered jointly by the Center for Computational Science and Engineering (CCSE) and the host departments, with the emphasis of thesis research activities being the development of new computational methods and/or the innovative application of computational techniques to important problems in engineering and science. For more information, see the full program description (*https://catalog.mit.edu/interdisciplinary/graduate-programs/computational-science-engineering*) under Interdisciplinary Graduate Programs.

Leaders for Global Operations

The 24-month Leaders for Global Operations (LGO) (*https://catalog.mit.edu/interdisciplinary/graduate-programs/leaders-global-operations*) program combines graduate degrees in engineering and management for those with previous postgraduate work experience and strong undergraduate degrees in a technical field. During the two-year program, students complete a six-month internship at one of LGO's partner companies, where they conduct research that forms the basis of a dual-degree thesis. Students finish the program with two MIT degrees: an MBA (or SM in management) and an SM from one of eight engineering programs, some of which have optional or required LGO tracks. After graduation, alumni lead strategic initiatives in high-tech, operations, and manufacturing companies.

Microbiology

The MIT Microbiology Graduate PhD Program (*https://catalog.mit.edu/interdisciplinary/graduate-programs/microbiology*) is an interdepartmental, interdisciplinary program that provides students broad exposure to underlying elements of modern microbiological research and engineering, and depth in specific areas of microbiology during the student‘s thesis work. MIT has a long-standing tradition of excellence in microbiological research; currently, more than 50 faculty from different departments study or use microbes in significant ways in their research. The program integrates educational resources across the participating departments to build connections among faculty with shared interests from different units and to build an educational community for training students in the study of microbial systems. Students apply to the Microbiology program and conduct research in the labs of faculty in one of the participating departments: Biology;

Biological Engineering; Chemical Engineering; Chemistry; Civil and Environmental Engineering; Earth, Atmospheric and Planetary Sciences; Electrical Engineering and Computer Science; Materials Sciences and Engineering; Media Arts and Sciences; and Physics. Graduates of this program will be prepared to enter a range of fields in microbial science and engineering and will have excellent career options in academic, industrial, and government settings.

Polymers and Soft Matter

The Program in Polymers and Soft Matter (PPSM) (*http://polymerscience.mit.edu*) offers students from participating departments an interdisciplinary core curriculum in polymer science and engineering, exposure to the broader polymer community through seminars, contact with visitors from industry and academia, and interdepartmental collaboration while working towards a PhD or ScD degree.

Research opportunities include functional polymers, controlled drug delivery, nanostructured polymers, polymers at interfaces, biomaterials, molecular modeling, polymer synthesis, biomimetic materials, polymer mechanics and rheology, self-assembly, and polymers in energy. The program is described in more detail (*https://catalog.mit.edu/interdisciplinary/graduate-programs/polymers-soft-matter*) under Interdisciplinary Graduate Programs.

Financial Support

The department has a wide variety of financial support options for graduate students, including teaching and research assistantships, fellowships, and loans. Information about financial assistance may be obtained by writing to the Graduate Student Office, but consideration for awards cannot be given before admissions decisions have been made.

Inquiries

For additional information concerning graduate programs, admissions, financial aid, and assistantships, contact the Graduate Student Office (*chemegrad@mit.edu*), Department of Chemical Engineering, Room 66-366, 617-253-4579.

Faculty and Teaching Staff

Kristala L. Jones Prather, PhD
Arthur D. Little Professor
Professor of Chemical Engineering
Head, Department of Chemical Engineering

Bradley D. Olsen, PhD
Alexander and I. Michael Kasser (1960) Professor
Professor of Chemical Engineering
Executive Officer, Department of Chemical Engineering

Professors

Daniel Griffith Anderson, PhD
Professor of Chemical Engineering
Core Faculty, Institute for Medical Engineering and Science

Robert C. Armstrong, PhD
Chevron Professor Post-Tenure
Professor Post-Tenure of Chemical Engineering

Paul I. Barton, PhD
Lammot du Pont Professor of Chemical Engineering

Martin Z. Bazant, PhD
E. G. Roos Professor
Professor of Chemical Engineering
Professor of Applied Mathematics

Daniel Blankschtein, PhD
Herman P. Meissner (1929) Professor of Chemical Engineering

Richard D. Braatz, PhD
Edwin R. Gilliland Professor
Professor of Chemical Engineering

Fikile R. Brushett, PhD
Professor of Chemical Engineering

Arup K. Chakraborty, PhD
John M. Deutch Institute Professor
Robert T. Haslam (1911) Professor in Chemical Engineering
Professor of Chemistry
Professor of Physics
Core Faculty, Institute for Medical Engineering and Science

Clark K. Colton, PhD
Professor of Chemical Engineering

Mircea Dincă, PhD
W. M. Keck Professor of Energy
Professor of Chemistry
Professor of Chemical Engineering
(On leave)

Patrick S. Doyle, PhD
Robert T. Haslam (1911) Professor of Chemical Engineering
(On sabbatical, spring)

William H. Green Jr, PhD
Hoyt Hottel Professor of Chemical Engineering

Paula T. Hammond, PhD
Institute Professor
Vice Provost for Faculty
Professor of Chemical Engineering

T. Alan Hatton, PhD
Ralph Landau (1941) Professor Post-Tenure
Professor Post-Tenure of Chemical Engineering

Klavs F. Jensen, PhD
Warren K. Lewis Professor Post-Tenure of Chemical Engineering
Professor Post-Tenure of Materials Science and Engineering

Jesse Kroll, PhD
Professor of Civil and Environmental Engineering
Professor of Chemical Engineering

Heather J. Kulik, PhD
Professor of Chemical Engineering
Professor of Chemistry

Robert Langer, ScD
David H. Koch (1962) Institute Professor
Professor of Chemical Engineering
Professor of Mechanical Engineering
Professor of Biological Engineering
Affiliate Faculty, Institute for Medical Engineering and Science

Douglas A. Lauffenburger, PhD
Ford Foundation Professor
Professor of Biological Engineering
Professor of Chemical Engineering
Professor of Biology

J. Christopher Love, PhD
Professor of Chemical Engineering

Yuriy Román, PhD
Robert T. Haslam (1911) Professor of Chemical Engineering
Professor of Chemistry
(On leave)

Gregory C. Rutledge, PhD
Lammot Dupont Professor of Chemical Engineering

Hadley Sikes, PhD
Professor of Chemical Engineering

George Stephanopoulos, PhD
Arthur Dehon Little Professor Post-Tenure
Professor Post-Tenure of Chemical Engineering

Gregory Stephanopoulos, PhD
Willard Henry Dow Professor of Chemical Engineering

Michael S. Strano, PhD
Carbon P. Dubbs Professor of Chemical Engineering

Yogesh Surendranath, PhD
Professor of Chemistry
Professor of Chemical Engineering

William A. Tisdale, PhD
Professor of Chemical Engineering

Bernhardt L. Trout, PhD
Raymond F. Baddour Professor
Professor of Chemical Engineering

Karl Dane Wittrup, PhD
Carbon P. Dubbs Professor of Chemical Engineering
Professor of Biological Engineering

Associate Professors
Kwanghun Chung, PhD
Associate Professor of Chemical Engineering
Associate Professor of Brain and Cognitive Sciences
Core Faculty, Institute for Medical Engineering and Science

Connor W. Coley, PhD
Class of 1957 Career Development Professor
Associate Professor of Chemical Engineering
Associate Professor of Electrical Engineering and Computer Science

Brandon J. DeKosky, PhD
Phillip and Susan Ragon Career Development Professor of Chemical Engineering
Associate Professor of Chemical Engineering

Zachary P. Smith, PhD
Robert N. Noyce Career Development Professor
Associate Professor of Chemical Engineering

Assistant Professors
Ariel L. Furst, PhD
Paul M. Cook Career Development Professor
Assistant Professor of Chemical Engineering

Kate E. Galloway, PhD
W. M. Keck Career Development Professor in Biomedical Engineering
Assistant Professor of Chemical Engineering

Qin Maggie Qi, PhD
James R. Mares ’24 Career Development Chair
Assistant Professor of Chemical Engineering

Sungho Shin, PhD
Texaco-Mangelsdorf Assistant Professor in Chemical Engineering

Professors of the Practice
Allan S. Myerson, PhD
Professor of the Practice of Chemical Engineering

Associate Professors of the Practice
Javit A. Drake, PhD
Associate Professor of the Practice of Chemical Engineering

Senior Lecturers
Robert J. Fisher, PhD
Senior Lecturer in Chemical Engineering

Robert T. Hanlon, ScD
Senior Lecturer in Chemical Engineering

Lecturers
Charles Baker, MS
Lecturer in Chemical Engineering

Thomas J. Blacklock, PhD
Lecturer in Chemical Engineering

Daniel Adam Doneson, PhD
Lecturer in Chemical Engineering

Joey Gu, PhD
Lecturer in Chemical Engineering

Jean-François P. Hamel, PhD
Lecturer in Chemical Engineering

Kathryn Elizabeth Hansen, PhD
Lecturer in Chemical Engineering

Peter J. Hansen, PhD
Lecturer in Chemical Engineering

Thomas A. Kinney, PhD
Lecturer in Chemical Engineering

Alethia Mariotta, JD
Lecturer in Chemical Engineering

Luis Perez-Breva, PhD
Lecturer in Chemical Engineering

Michael S. Sarli, MS
Lecturer in Chemical Engineering

Rory G. Schacter, PhD
Lecturer in Chemical Engineering

Brian E. Stutts, PhD
Lecturer in Chemical Engineering

Research Staff

Research Scientists
Lev E. Bromberg, PhD
Research Scientist in Chemical Engineering

Felice Frankel, BS
Research Scientist in Chemical Engineering

Professors Emeriti

Robert A. Brown, PhD
Professor Emeritus of Chemical Engineering

Robert E. Cohen, PhD
Raymond A. and Helen E. St. Laurent Professor Emeritus
Professor Emeritus of Chemical Engineering

Charles L. Cooney, PhD
Robert T. Haslam (1911) Professor Emeritus
Professor Emeritus of Chemical Engineering

William M. Deen, PhD
Carbon P. Dubbs Professor Emeritus of Chemical Engineering

Lawrence B. Evans, PhD
Professor Emeritus of Chemical Engineering

Karen K. Gleason, PhD
Alexander and I. Michael Kasser (1960) Professor Emerita
Professor Emerita of Chemical Engineering

Gregory J. McRae, PhD
Professor Emeritus of Chemical Engineering

Herbert Harold Sawin, PhD
Professor Emeritus of Chemical Engineering
Professor Emeritus of Electrical Engineering

Kenneth A. Smith, PhD
Professor Emeritus of Chemical Engineering

Jefferson W. Tester, PhD
Professor Emeritus of Chemical Engineering

Preetinder S. Virk, ScD
Associate Professor Emeritus of Chemical Engineering

10.00 Molecule Builders
Prereq: Chemistry (GIR) and Physics I (GIR)
U (Spring)
1-3-2 units

Project-based introduction to the applications of engineering design at the molecular level. Working in teams, students complete an open-ended design project that focuses on a topic such as reactor or biomolecular engineering, chemical process design, materials and polymers, or energy. Provides students practical exposure to the field of chemical engineering as well as potential opportunities to continue their project designs in national/international competitions. Limited to 36; preference to first year students.
B. D. Olsen

10.000 Engineering Molecular Marvels: Careers and ChemE at MIT
Prereq: None
U (Spring)
Not offered regularly; consult department
2-0-0 units

Exposes students to the ways in which chemical technologies have profoundly altered the course of history. Discusses the next century's great challenges, such as curing cancer and supplying the planet's surging demand for clean water, food and energy, sustainably. Provides an overview of how ChemE students apply fundamental engineering principles and leverage technology, from molecules to systems, in the pursuit of practical solutions for these problems and more. Subject can count toward the 6-unit discovery-focused credit limit for first year students.
T. A. Kinney

10.01 Ethics for Engineers
Engineering School-Wide Elective Subject.
Offered under: 1.082, 2.900, 6.9320, 10.01, 16.676
Subject meets with 6.9321, 20.005
Prereq: None
U (Fall, Spring)
2-0-4 units

Explores how to be an ethical engineer. Students examine engineering case studies alongside key readings by foundational ethical thinkers from Aristotle to Martin Luther King, Jr., and investigate which ethical approaches are best and how to apply them. Topics include justice, rights, cost-benefit analysis, safety, bias, genetic engineering, climate change, and the promise and peril of AI. Discussion-based, with the aim of introducing students to new ways of thinking. All sections cover the same core ethical frameworks, but some sections have a particular focus for case studies, such as bioengineering, or have an in-depth emphasis on particular thinkers. The subject is taught in separate sections. Students are eligible to take any section regardless of their registered subject number. For 20.005, students additionally undertake an ethical-technical analysis of a BE-related topic of their choosing.
D. A. Lauffenburger, B. L. Trout

10.02 Foundations of Entrepreneurship for Engineers
Prereq: None
U (Spring)
Not offered regularly; consult department
3-0-9 units

Studies economic and leadership foundations of entrepreneurship as they relate to engineering. Case studies illustrate major impacts of engineering on the world and examine the leaders responsible for such impacts. Authors include Franklin, Keynes, Leonardo, Lincoln, Locke, Machiavelli, Marx, Schmidt, Schumpeter, Smith, Thiel, and Tocqueville. Discusses topics such as the difference between an entrepreneur and a manager, the entrepreneur as founder, and characteristics of principled entrepreneurship.
D. Doneson, B. L. Trout

10.03[J] Advances in Biomanufacturing
Same subject as 7.458[J]
Subject meets with 7.548[J], 10.53[J]
Prereq: None
U (Spring; second half of term)
1-0-2 units

Seminar examines how biopharmaceuticals, an increasingly important class of pharmaceuticals, are manufactured. Topics range from fundamental bioprocesses to new technologies to the economics of biomanufacturing. Also covers the impact of globalization on regulation and quality approaches as well as supply chain integrity. Students taking graduate version complete additional assignments.
J. C. Love, A. Sinskey, S. Springs

10.04 A Philosophical History of Energy
Prereq: None
U (Spring)
Not offered regularly; consult department
3-0-9 units

Philosophic and historical approach to conceptions of energy through the 19th century. Relation of long standing scientific and philosophic problems in the field of energy to 21st-century debates. Topics include the development of thermodynamics and kinetic theories, the foundation of the scientific project, the classical view of energy, and the harnessing of nature. Authors include Bacon, Boltzmann, Carnot, Compte, Descartes, Gibbs, Plato, Aristotle, Leibniz, Kant, Hegel, Mill, Peirce, Whitehead, and Maxwell. Key texts and controversies form topics of weekly writing assignments and term papers.
B. L. Trout, A. Schulman

10.05 Foundational Analyses of Problems in Energy and the Environment
Prereq: None
U (Spring)
Not offered regularly; consult department
3-0-9 units

Investigates key texts and papers on the foundational thought of current issues in energy and environmental science. Builds an understanding of key debates (scientific, ethical, and political). Aims to inform solutions to key problems related to procurement of energy and environmental degradation. Topics address alternative energy technologies and fossil fuel utilization and emissions, especially carbon dioxide, carbon dioxide sequestration, and geoengineering. Foundational readings from Homer and Greek playwrights, Aristotle, Genesis, Bacon, Locke, Rousseau, Coleridge, Carnot, Clausius, Marx, Heidegger, Carson, Gore, Singer, and Brundtland. Assignments include weekly analyses of readings, videos and related engineering calculations in addition to a final project. Limited to 18.
B. L. Trout

10.06 Advanced Topics in Ethics for Engineers
Prereq: 10.01, 10.05, or permission of instructor
U (Fall, Spring)
Not offered regularly; consult department
2-0-4 units
Can be repeated for credit.

In-depth study of varying advanced topics in ethics for engineers. Focuses on foundational works and their significance for the choices that engineers make, both as students and as practicing engineers. Each semester, different works and topics, based on current and perennial issues in ethics and engineering, will be chosen in order to explore facets of the extremely complex and varied subject of the place of engineering for the individual and society. Examples of topics include genetic engineering and what it means to be human, artificial intelligence and thought, the scope and limits of engineering, and engineering and freedom. May be repeated for credit with permission of instructor. Limited to 20.
B. L. Trout, D. Doneson

10.07[J] Debating About Society and Engineering
Same subject as 21W.733[J]
Prereq: None
U (Spring)
Not offered regularly; consult department
3-0-6 units. HASS-H

Presents basic principles of argumentation and persuasive communication, and introduces students to thought-provoking, persuasive texts about science and engineering. Analysis of texts and practices together with case studies form the basis for students' weekly assignments. Students debate such topics as the future of biotechnology, genetic engineering, AI, climate change, social bias, and the connection between engineering and society. Includes oral presentations. Limited to 18.
E. Schiappa, B. L. Trout

10.08 Cultural Studies for Chemical Engineering Graduate Students
Prereq: None
G (Fall)
Not offered regularly; consult department
2-0-4 units

Seminar explores some of the key cultural developments of human beings and their related engineering aspects together with insights into the evolution of chemical engineering. Begins with discussion of Warren K. Lewis on culture and civilization, in addition to other chemical engineering luminaries, Rutherford Aris and John Prausnitz, and Sam Florman. Following their leads, seminar addresses key developments in Greek culture, followed by Renaissance culture, and culminating with contemporary culture. Discusses the influence of chemical engineering throughout the term, but focuses on broader cultural understanding as advocated by Lewis and Aris. Weekly meetings and study question responses are complemented with direct experience of culture and its connection to engineering. Includes guests with various expertise in culture and chemical engineering.
B. L. Trout

10.09 Models of Molecular Systems: from Newtonian Mechanics to Machine Learning
Prereq: None
U (Spring)
2-0-7 units

Explores the significance and applicability of models of molecular systems, starting from modern modeling and going back to ancient possibilities. Newtonian mechanics and optics to thermodynamics, statistical mechanics, quantum mechanics, simulations, and machine learning are covered together with foundational modern and ancient concepts of modeling. Addresses the questions of what models of molecular systems aim towards, what makes a good model, and how one should think about model robustness from phenomenological to first-principles models and from concrete to abstract. Foundational readings inform current approaches, applications including biology, optics and vision, and atomic science. Work consists of weekly assignments, class participation, and a final project.
B. L. Trout

10.10 Introduction to Chemical Engineering
Prereq: Chemistry (GIR) and Physics I (GIR); *Coreq: 18.03*
U (Fall, Spring)
4-0-8 units

Explores the diverse applications of chemical engineering through example problems designed to build computer skills and familiarity with the elements of engineering design. Solutions require application of fundamental concepts of mass and energy conservation to batch and continuous systems involving chemical and biological processes. Problem-solving exercises distributed among lectures and recitation.
K. L. J. Prather, T. Kinney

10.213 Chemical and Biological Engineering Thermodynamics
Prereq: 5.601 and 10.10
U (Spring)
4-0-8 units

Thermodynamics of multicomponent, multiphase chemical and biological systems. Applications of first, second, and third laws of thermodynamics to open and closed systems. Properties of mixtures, including colligative properties, chemical reaction equilibrium, and phase equilibrium; non-ideal solutions; power cycles; refrigeration; separation systems.
K. K. Gleason, H. D. Sikes

10.22 Molecular Engineering
Prereq: 5.60 and 10.213
U (Spring)
Not offered regularly; consult department
3-0-9 units

Introduces molecular concepts in relation to engineering thermodynamics. Includes topics in statistical mechanics, molecular description of gases and liquids, property estimation, description of equilibrium and dynamic properties of fluids from molecular principles, and kinetics of activated processes. Also covers some basic aspects of molecular simulation and applications in systems of engineering interest.
G. C. Rutledge, P. S. Doyle

10.25 Industrial Chemistry and Chemical Process Pathways
Prereq: Chemistry (GIR), 10.213, and 10.37
G (Fall)
Not offered regularly; consult department
3-0-6 units

Chemical and engineering principles involved in creation and operation of viable industrial processes. Topics: analysis of process chemistry by p-pathways (i.e., radical, ionic, and pericyclic reactions of organic syntheses) and d-pathways (i.e., catalysis by transition-metal complexes). Use of reaction mechanisms for inference of co-product formation, kinetics, and equilibria: process synthesis logic related to reaction selectivity, recycle, separations. Illustrations drawn from current and contemplated commercial practice.
P. S. Virk

10.26 Chemical Engineering Projects Laboratory
Subject meets with 10.27, 10.29
Prereq: (10.302 and (2.671, 5.310, 7.003[J], 12.335, 20.109, (1.106 and 1.107), or (5.351, 5.352, and 5.353))) or permission of instructor
U (Spring)
3-8-4 units

Projects in applied chemical engineering research. Students work in teams on one project for the term. Projects often suggested by local industry. Includes training in project planning and project management, execution of experimental work, data analysis, oral presentation, individual and collaborative report writing.
G. C. Rutledge

10.27 Energy Engineering Projects Laboratory
Subject meets with 10.26, 10.29
Prereq: (10.302 and (2.671, 5.310, 7.003[J], 12.335, 20.109, (1.106 and 1.107), or (5.351, 5.352, and 5.353))) or permission of instructor
U (Spring)
3-8-4 units

Projects in applied energy engineering research. Students work in teams on one project for the term. Projects often suggested by local industry. Includes training in project planning and project management, execution of experimental work, data analysis, oral presentation, individual and collaborative report writing. Preference to Energy Studies minors.
G. C. Rutledge

10.28 Chemical-Biological Engineering Laboratory
Prereq: ((5.07[J] or 7.05) and (5.310 or 7.003[J])) or permission of instructor
U (Fall)
2-8-5 units
Credit cannot also be received for 10.28B

Introduces the complete design of the bioprocess: from vector selection to production, separation, and characterization of recombinant products. Utilize concepts from many fields, such as, chemical and electrical engineering, and biology. Student teams work through parallel modules spanning microbial fermentation and animal cell culture. With the bioreactor at the core of the experiments, students study cell metabolism and biological pathways, kinetics of cell growth and product formation, oxygen mass transport, scale-up and techniques for the design of process control loops. Introduces novel bioreactors and powerful analytical instrumentation. Downstream processing and recombinant product purification also included. Credit cannot also be received for 10.28A. Enrollment limited.
J.-F. Hamel

10.28A Chemical-Biological Engineering Laboratory I: Introduction to Lab Experiments
Prereq: ((5.07[J] or 7.05) and (5.310 or 7.003[J])) or permission of instructor
U (IAP, Spring)
Not offered regularly; consult department
1-3-0 units

First in a two-subject sequence that spans IAP and spring term, and covers the same content as 10.28; see 10.28 for description. Course utilizes online learning technologies and simulations in addition to traditional lab experiments. 10.28A comprises the major lab portion of the subject. Credit cannot also be received for 10.28. Enrollment limited.
J.-F. Hamel

10.28B Chemical-Biological Engineering Laboratory II: Long-term, Online and Simulated Experiments
Prereq: 10.28A
U (Spring)
Not offered regularly; consult department
1-2-8 units
Credit cannot also be received for 10.28

Second in a two-subject sequence that spans IAP and spring term, and covers the same content as 10.28; see 10.28 for description. Course utilizes online learning technologies and simulations in addition to traditional lab experiments. 10.28B comprises the simulation portion of the subject, and most of the communication component. Enrollment limited.
J.-F. Hamel

10.29 Biological Engineering Projects Laboratory
Subject meets with 10.26, 10.27
Prereq: (10.302 and (2.671, 5.310, 7.003[J], 12.335, 20.109, (1.106 and 1.107), or (5.351, 5.352, and 5.353))) or permission of instructor
U (Spring)
3-8-4 units

Projects in applied biological engineering research. Students work in teams on one project for the term. Projects often suggested by local industry. Includes training in project planning and project management, execution of experimental work, data analysis, oral presentation, individual and collaborative report writing.
G. C. Rutledge

10.291[J] Introduction to Sustainable Energy
Same subject as 2.650[J], 22.081[J]
Subject meets with 1.818[J], 2.65[J], 10.391[J], 11.371[J], 22.811[J]
Prereq: Permission of instructor
Acad Year 2024-2025: Not offered
Acad Year 2025-2026: U (Fall)
3-1-8 units

See description under subject 22.081[J]. Limited to juniors and seniors.
M. W. Golay

10.301 Fluid Mechanics
Prereq: 10.10 and 18.03
U (Spring)
4-0-8 units. REST

Introduces the mechanical principles governing fluid flow. Stress in a fluid. Conservation of mass and momentum, using differential and integral balances. Elementary constitutive equations. Hydrostatics. Exact solutions of the Navier-Stokes equations. Approximate solutions using control volume analysis. Mechanical energy balances and Bernoulli's equation. Dimensional analysis and dynamic similarity. Introduces boundary-layer theory and turbulence.
P. S. Doyle, F. R. Brushett

10.302 Transport Processes
Prereq: (5.601, 10.213, and 10.301) or permission of instructor
U (Fall)
4-0-8 units

Principles of heat and mass transfer. Steady and transient conduction and diffusion. Radiative heat transfer. Convective transport of heat and mass in both laminar and turbulent flows. Emphasis on the development of a physical understanding of the underlying phenomena and upon the ability to solve real heat and mass transfer problems of engineering significance.
W. A. Tisdale, B. DeKosky

10.31 Nanoscale Energy Transport Processes
Subject meets with 10.51
Prereq: ((2.51 or 10.302) and (3.033 or 5.61)) or permission of instructor
Acad Year 2024-2025: U (Fall)
Acad Year 2025-2026: Not offered
3-0-9 units

Explores the impact of nanoscale phenomena on macroscale transport of energy-carrying molecules, phonons, electrons, and excitons. Studies the effect of structural and energetic disorder, wave-like vs. particle-like transport, quantum and classical size effects, and quantum coherence. Emphasizes quantitative analysis, including the Boltzmann transport equation, Einstein relation, Wiedemann-Franz law, and Marcus electron transfer theory. Also addresses percolation theory and the connection to energy conversion technologies, such as solar cells, thermoelectrics, and LEDs. Students taking graduate version complete additional assignments.
W. A. Tisdale

10.32 Separation Processes
Prereq: 10.213 and 10.302
U (Spring)
3-0-6 units

General principles of separation by equilibrium and rate processes. Staged cascades. Applications to distillation, absorption, adsorption, and membrane processes. Use of material balances, phase equilibria, and diffusion to understand and design separation processes.
T. A. Hatton

10.321 Design Principles in Mammalian Systems and Synthetic Biology
Subject meets with 10.521
Prereq: 7.05 and 18.03
Acad Year 2024-2025: U (Fall)
Acad Year 2025-2026: Not offered
3-0-6 units

Focuses on the layers of design, from molecular to large networks, in mammalian biology. Formally introduces concepts in the emerging fields of mammalian systems and synthetic biology, including engineering principles in neurobiology and stem cell biology. Exposes advanced students from quantitative backgrounds to problem-solving opportunities at the interface of molecular biology and engineering. Students taking graduate version complete additional assignments.
K. E. Galloway

10.333 Introduction to Modeling and Simulation
Engineering School-Wide Elective Subject.
Offered under: 1.021, 3.021, 10.333, 22.00
Prereq: 18.03 or permission of instructor
U (Spring)
4-0-8 units. REST

See description under subject 3.021.
M. Buehler

10.34 Numerical Methods Applied to Chemical Engineering
Prereq: Permission of instructor
G (Fall)
3-0-6 units

Numerical methods for solving problems arising in heat and mass transfer, fluid mechanics, chemical reaction engineering, and molecular simulation. Topics: numerical linear algebra, solution of nonlinear algebraic equations and ordinary differential equations, solution of partial differential equations (e.g., Navier-Stokes), numerical methods in molecular simulation (dynamics, geometry optimization). All methods are presented within the context of chemical engineering problems. Familiarity with structured programming is assumed.
C. Coley, W. Green

10.345 Fundamentals of Metabolic and Biochemical Engineering: Applications to Biomanufacturing
Subject meets with 10.545
Prereq: 5.07[J], 7.05, or permission of instructor
U (Spring)
Not offered regularly; consult department
3-0-9 units

Examines the fundamentals of cell and metabolic engineering for biocatalyst design and optimization, as well as biochemical engineering principles for bioreactor design and operation, and downstream processing. Presents applications of microbial processes for production of commodity and specialty chemicals and biofuels in addition to mammalian cell cultures for production of biopharmaceuticals. Students taking graduate version complete additional assignments.
Gr. Stephanopoulos

10.352 Modern Control Design
Subject meets with 10.552
Prereq: 18.03 or permission of instructor
U (Fall)
Not offered regularly; consult department
3-0-6 units

Covers modern methods for dynamical systems analysis, state estimation, controller design, and related topics. Uses example applications to demonstrate Lyapunov and linear matrix inequality-based methods that explicitly address actuator constraints, nonlinearities, and model uncertainties. Students taking graduate version complete additional assignments. Limited to 30.
R. D. Braatz

10.353 Model Predictive Control
Subject meets with 10.553
Prereq: 18.03 or permission of instructor
U (Fall)
Not offered regularly; consult department
3-0-6 units

Provides an introduction to the multivariable control of dynamical systems with constraints on manipulated, state, and output variables. Covers multiple mathematical formulations that are popular in academia and industry, including dynamic matrix control and state-space model predictive control of uncertain, nonlinear, and large-scale systems. Uses numerous real industrial processes as examples. Students taking graduate version complete additional assignments.
R. D. Braatz

10.354[J] Process Data Analytics
Same subject as 2.874[J]
Subject meets with 2.884[J], 10.554[J]
Prereq: 18.03 or permission of instructor
Acad Year 2024-2025: U (Fall)
Acad Year 2025-2026: Not offered
4-0-8 units

Provides an introduction to data analytics for manufacturing processes. Topics include chemometrics, discriminant analysis, hyperspectral imaging, machine learning, big data, Bayesian methods, experimental design, feature spaces, and pattern recognition as relevant to manufacturing process applications (e.g., output estimation, process control, and fault detection, identification and diagnosis). Students taking graduate version complete additional assignments.
R. D. Braatz, B. Anthony

10.37 Chemical Kinetics and Reactor Design
Prereq: 10.213 and 10.302
U (Spring)
3-0-9 units

Applies the concepts of reaction rate, stoichiometry and equilibrium to the analysis of chemical and biological reacting systems. Derivation of rate expressions from reaction mechanisms and equilibrium or steady state assumptions. Design of chemical and biochemical reactors via synthesis of chemical kinetics, transport phenomena, and mass and energy balances. Topics: chemical/biochemical pathways; enzymatic, pathway and cell growth kinetics; batch, plug flow and well-stirred reactors for chemical reactions and cultivations of microorganisms and mammalian cells; heterogeneous and enzymatic catalysis; heat and mass transport in reactors, including diffusion to and within catalyst particles and cells or immoblized enzymes.
Gr. Stephanopoulos, Y. Roman

10.380[J] Viruses, Pandemics, and Immunity
Same subject as 5.002[J], HST.438[J]
Subject meets with 5.003[J], 8.245[J], 10.382[J], HST.439[J]
Prereq: None
U (Spring)
Not offered regularly; consult department
2-0-1 units

See description under subject HST.438[J]. Preference to first-year students; all others should take HST.439[J].
A. Chakraborty

10.382[J] Viruses, Pandemics, and Immunity
Same subject as 5.003[J], 8.245[J], HST.439[J]
Subject meets with 5.002[J], 10.380[J], HST.438[J]
Prereq: None
U (Spring)
Not offered regularly; consult department
2-0-1 units

See description under subject HST.439[J]. HST.438[J] intended for first-year students; all others should take HST.439[J].
A. Chakraborty

10.390[J] Fundamentals of Advanced Energy Conversion
Same subject as 2.60[J]
Subject meets with 2.62[J], 10.392[J], 22.40[J]
Prereq: 2.006, (2.051 and 2.06), or permission of instructor
U (Spring)
4-0-8 units

See description under subject 2.60[J].
A. F. Ghoniem, W. Green

10.391[J] Sustainable Energy
Same subject as 1.818[J], 2.65[J], 11.371[J], 22.811[J]
Subject meets with 2.650[J], 10.291[J], 22.081[J]
Prereq: Permission of instructor
Acad Year 2024-2025: Not offered
Acad Year 2025-2026: G (Fall)
3-1-8 units

See description under subject 22.811[J].
M. W. Golay

10.392[J] Fundamentals of Advanced Energy Conversion
Same subject as 2.62[J], 22.40[J]
Subject meets with 2.60[J], 10.390[J]
Prereq: 2.006, (2.051 and 2.06), or permission of instructor
G (Spring)
4-0-8 units

See description under subject 2.62[J].
A. F. Ghoniem, W. Green

10.40 Chemical Engineering Thermodynamics
Prereq: 10.213
G (Fall)
4-0-8 units

Basic postulates of classical thermodynamics. Application to transient open and closed systems. Criteria of stability and equilibria. Constitutive property models of pure materials and mixtures emphasizing molecular-level effects using the formalism of statistical mechanics. Phase and chemical equilibria of multicomponent systems. Applications emphasized through extensive problem work relating to practical cases.
B. Olsen, A. Charkraborty

10.407[J] Money for Startups
Same subject as 2.916[J]
Prereq: None
G (Spring; second half of term)
2-0-4 units

Introduction to the substance and process of funding technology startups. Topics include a comparative analysis of various sources of capital; templates to identify the optimal investor; legal frameworks, US and offshore, of the investment process and its related jargon; an introduction to understanding venture capital as a business; and market practice and standards for term sheet negotiation. Emphasizes strategy as well as tactics necessary to negotiate and build effective, long-term relationships with investors, particularly venture capital firms (VCs).
S. Loessberg, D. P. Hart

10.421[J] Energy Systems for Climate Change Mitigation
Same subject as 1.067[J], IDS.065[J]
Subject meets with 1.670[J], 10.621[J], IDS.521[J]
Prereq: (Calculus I (GIR), Chemistry (GIR), and Physics I (GIR)) or permission of instructor
U (Fall)
3-0-9 units

See description under subject IDS.065[J]. Preference to students in the Energy Studies or Environment and Sustainability minors.
J. Trancik

10.424 Pharmaceutical Engineering
Subject meets with 10.524
Prereq: 10.213
Acad Year 2024-2025: Not offered
Acad Year 2025-2026: U (Fall)
3-0-6 units

Presents engineering principles and unit operations involved in the manufacture of small molecules pharmaceuticals, from the isolation of purified active pharmaceutical ingredients (API) to the final production of drug product. Regulatory issues include quality by design and process analytical technologies of unit operations, such as crystallization, filtration, drying, milling, blending, granulation, tableting and coating. Also covers principles of formulation for solid dosage forms and parenteral drugs. Students taking graduate version complete additional assignments. Limited to 50.
A. S. Myerson

10.426 Electrochemical Energy Systems
Subject meets with 10.626
Prereq: 10.302 or permission of instructor
U (Fall)
3-0-9 units

Introduces electrochemical energy systems from the perspective of thermodynamics, kinetics, and transport. Surveys analysis and design of electrochemical reactions and processes by integrating chemical engineering fundamentals with knowledge from diverse fields, including chemistry, electrical engineering, and materials science. Includes applications to fuel cells, electrolyzers, and batteries. Students taking graduate version complete additional assignments.
M. Z. Bazant

10.43 Introduction to Interfacial Phenomena
Prereq: 10.213 or introductory subject in thermodynamics or physical chemistry
G (Spring)
Not offered regularly; consult department
3-0-6 units

Introduces fundamental and applied aspects of interfacial systems. Theory of capillarity. Experimental determination of surface and interfacial tensions. Thermodynamics of interfaces. The Gibbs adsorption equation. Charged interfaces. Surfactant adsorption at interfaces. Insoluble monolayers. Curvature effects on the equilibrium state of fluids. Nucleation and growth. Fundamentals of wetting and contact angle. Adhesion, cohesion, and spreading. Wetting of textured surfaces. Super-hydrophilic and super-hydrophobic surfaces. Self-cleaning surfaces.
D. Blankschtein

10.437[J] Computational Chemistry
Same subject as 5.697[J]
Subject meets with 5.698[J], 10.637[J]
Prereq: Permission of instructor
Acad Year 2024-2025: Not offered
Acad Year 2025-2026: U (Fall)
3-0-9 units

Addresses both the theory and application of first-principles computer simulations methods (i.e., quantum, chemical, or electronic structure), including Hartree-Fock theory, density functional theory, and correlated wavefunction methods. Covers enhanced sampling, ab initio molecular dynamics, and transition-path-finding approaches as well as errors and accuracy in total and free energies. Discusses applications such as the study and prediction of properties of chemical systems, including heterogeneous, molecular, and biological catalysts (enzymes), and physical properties of materials. Students taking graduate version complete additional assignments. Limited to 35; no listeners.
H. J. Kulik

10.441[J] Molecular and Engineering Aspects of Biotechnology
Same subject as 7.37[J], 20.361[J]
Prereq: (7.06 and (2.005, 3.012, 5.60, or 20.110[J])) or permission of instructor
Acad Year 2024-2025: Not offered
Acad Year 2025-2026: U (Spring)
4-0-8 units
Credit cannot also be received for 7.371

See description under subject 7.37[J].
Staff

10.442 Biochemical Engineering and Biomanufacturing Principles
Subject meets with 10.542
Prereq: (Biology (GIR), 5.07[J], and 10.37) or permission of instructor
U (Spring)
3-0-6 units

Explores the interactions of chemical engineering, biochemical engineering, and microbiology with particular emphasis on applications to bioprocess development. Examines mathematical representations of microbial systems, especially with regard to the kinetics of growth, death, and metabolism. Discusses the fundamentals of bioreactor design and operation, including continuous fermentation, mass transfer, and agitation. Examples encompass both enzyme and whole cell systems. Presents concepts in process development for microbial and animal cell cultures, with considerations towards production of biological products ranging from chiral specialty chemicals/pharmaceuticals to therapeutic proteins. Concludes with a discussion of aspects of cellular engineering and the role of molecular biology in addressing process development problems.
K. J. Prather

10.443 Future Medicine: Drug Delivery, Therapeutics, and Diagnostics
Subject meets with 10.643[J], HST.526[J]
Prereq: 5.12 or permission of instructor
U (Spring)
Not offered regularly; consult department
3-0-6 units

Aims to describe the direction and future of medical technology. Introduces pharmaceutics, pharmacology, and conventional medical devices, then transitions to drug delivery systems, mechanical/electric-based and biological/cell-based therapies, and sensors. Covers nano- and micro drug delivery systems, including polymer-drug conjugates, protein therapeutics, liposomes and polymer nanoparticles, viral and non-viral genetic therapy, and tissue engineering. Previous coursework in cell biology and organic chemistry recommended. Students taking graduate version complete additional assignments. Limited to 40.
D. G. Anderson

10.450 Process Dynamics, Operations, and Control
Prereq: 10.302 and 18.03
U (Spring)
Not offered regularly; consult department
3-0-6 units

Introduction to dynamic processes and the engineering tasks of process operations and control. Subject covers modeling the static and dynamic behavior of processes; control strategies; design of feedback, feedforward, and other control structures; model-based control; applications to process equipment.
Staff

10.466 Structure of Soft Matter
Subject meets with 10.566
Prereq: 5.60
U (Fall)
Not offered regularly; consult department
3-0-6 units

Provides an introduction to the basic thermodynamic language used for describing the structure of materials, followed by a survey of the scattering, microscopy and spectroscopic techniques for structure and morphology characterization. Applies these concepts to a series of case studies illustrating the diverse structures formed in soft materials and the common length, time and energy scales that unify this field. For students interested in studying polymer science, colloid science, nanotechnology, biomaterials, and liquid crystals. Students taking graduate version complete additional assignments.
B. D. Olsen

10.467 Polymer Science Laboratory
Prereq: 5.12 and (5.310, 7.003[J], 20.109, or permission of instructor)
U (Fall)
2-7-6 units

Experiments broadly aimed at acquainting students with the range of properties of polymers, methods of synthesis, and physical chemistry. Examples: solution polymerization of acrylamide, bead polymerization of divinylbenzene, interfacial polymerization of nylon 6,10. Evaluation of networks by tensile and swelling experiments. Rheology of polymer solutions and suspensions. Physical properties of natural and silicone rubber. Preference to Course 10 seniors and juniors.
Z. Smith

10.489 Concepts in Modern Heterogeneous Catalysis
Subject meets with 10.689
Prereq: 10.302 and 10.37
U (Spring)
Not offered regularly; consult department
3-0-6 units

Explores topics in the design and implementation of heterogeneous catalysts for chemical transformations. Emphasizes use of catalysis for environmentally benign and sustainable chemical processes. Lectures address concepts in catalyst preparation, catalyst characterization, quantum chemical calculations, and microkinetic analysis of catalytic processes. Shows how experimental and theoretical approaches can illustrate important reactive intermediates and transition states involved in chemical reaction pathways, and uses that information to help identify possible new catalysts that may facilitate reactions of interest. Draws examples from current relevant topics in catalysis. Includes a group project in which students investigate a specific topic in greater depth. Students taking graduate version complete additional assignments.
Y. Roman

10.490 Integrated Chemical Engineering
Prereq: 10.37
U (Fall, Spring)
3-0-6 units
Can be repeated for credit.

Presents and solves chemical engineering problems in an industrial context. Emphasis on the integration of fundamental concepts with approaches in process design, and on problems that demand synthesis, economic analysis, and process design; consideration of safety analysis, process dynamics and the use of process simulators and related tools to approach such problems. The specific application of these fundamental concepts will vary each term, and may include chemical, electrochemical, pharmaceutical, biopharmaceutical (biologic) or related processes, operated in batch, semi-batch, continuous or hybrid mode. May be repeated once for credit with permission of instructor.
Y. Roman, P. I. Barton

10.492A Integrated Chemical Engineering Topics I
Prereq: 10.301 and permission of instructor
U (Fall; first half of term)
2-0-4 units
Can be repeated for credit.

Chemical engineering problems presented and analyzed in an industrial context. Emphasizes the integration of fundamentals with material property estimation, process control, product development, and computer simulation. Integration of societal issues, such as engineering ethics, environmental and safety considerations, and impact of technology on society are addressed in the context of case studies. 10.37 and 10.302 required for certain topic modules. See departmental website for individual ICE-T module descriptions.
Staff

10.492B Integrated Chemical Engineering Topics I
Prereq: 10.301 and permission of instructor
U (Fall; second half of term)
2-0-4 units
Can be repeated for credit.

Chemical engineering problems presented and analyzed in an industrial context. Emphasizes the integration of fundamentals with material property estimation, process control, product development, and computer simulation. Integration of societal issues, such as engineering ethics, environmental and safety considerations, and impact of technology on society are addressed in the context of case studies. 10.37 and 10.302 required for certain topic modules. See departmental website for individual ICE-T module descriptions.
K. F. Jensen

10.493 Integrated Chemical Engineering Topics II
Prereq: 10.301 and permission of instructor
U (IAP; partial term)
2-0-4 units

Chemical engineering problems presented and analyzed in an industrial context. Emphasizes the integration of fundamentals with material property estimation, process control, product development, and computer simulation. Integration of societal issues, such as engineering ethics, environmental and safety considerations, and impact of technology on society are addressed in the context of case studies. 10.37 and 10.302 required for certain topic modules. See departmental website for individual ICE-T module descriptions.
J. Drake

10.494A Integrated Chemical Engineering Topics III
Prereq: 10.301 and permission of instructor
Acad Year 2024-2025: U (Spring; first half of term)
Acad Year 2025-2026: Not offered
2-0-4 units
Can be repeated for credit.

Chemical engineering problems presented and analyzed in an industrial context. Emphasizes the integration of fundamentals with material property estimation, process control, product development, and computer simulation. Integration of societal issues, such as engineering ethics, environmental and safety considerations, and impact of technology on society are addressed in the context of case studies. 10.37 and 10.302 required for certain topic modules. See departmental website for individual ICE-T module descriptions.
W. H. Green

10.494B Integrated Chemical Engineering Topics III
Prereq: 10.301 and permission of instructor
U (Spring; second half of term)
2-0-4 units
Can be repeated for credit.

Chemical engineering problems presented and analyzed in an industrial context. Emphasizes the integration of fundamentals with material property estimation, process control, product development, and computer simulation. Integration of societal issues, such as engineering ethics, environmental and safety considerations, and impact of technology on society are addressed in the context of case studies. 10.37 and 10.302 required for certain topic modules. See departmental website for individual ICE-T module descriptions.
D. G. Anderson

10.495 Molecular Design and Bioprocess Development of Immunotherapies
Subject meets with 10.595
Prereq: 7.06 or permission of instructor
Acad Year 2024-2025: Not offered
Acad Year 2025-2026: U (Fall)
3-0-6 units

Examines challenges and opportunities for applying chemical engineering principles to address the growing global burden of infectious disease, including drug-resistant strains and neglected pathogens. Topics include a historical overview of vaccines and immunotherapies, the molecular design considerations for new immunotherapies and adjuvants, the economic challenges for process development and manufacturing of immunotherapies, and new technologies for designing and assessing therapies. Case studies to cover topics for specific diseases. Students taking graduate version complete additional assignments.
J. C. Love

10.496[J] Design of Sustainable Polymer Systems
Same subject as 1.096[J]
Prereq: (10.213 and 10.301) or permission of instructor
U (Fall)
Not offered regularly; consult department
3-0-9 units

Capstone subject in which students are charged with redesigning consumable plastics to improve their recyclability and illustrate the potential future of plastic sourcing and management. Students engage with industry partners and waste handlers to delineate the design space and understand downstream limitations in waste treatment. Instruction includes principles of plastic design, polymer selection, cost estimation, prototyping, and the principles of sustainable material design. Students plan and propose routes to make enhanced plastic kits. Industry partners and course instructors select winning designs. Those students can elect to proceed to a semester of independent study in which prototype kits are fabricated (using polymer extrusion, cutting, 3D printing), potentially winning seed funds to translate ideas into real impacts. Preference to juniors and seniors in Courses 10, 1, and 2.
B. D. Olsen, D. Plata

10.50 Analysis of Transport Phenomena
Prereq: 10.301 and 10.302
G (Spring)
4-0-8 units

Unified treatment of heat transfer, mass transfer, and fluid mechanics, emphasizing scaling concepts in formulating models and analytical methods for obtaining solutions. Topics include conduction and diffusion, laminar flow regimes, convective heat and mass transfer, and simultaneous heat and mass transfer with chemical reaction or phase change.
M. Z. Bazant, M. Qi

10.51 Nanoscale Energy Transport Processes
Subject meets with 10.31
Prereq: ((2.51 or 10.302) and (3.033 or 5.61)) or permission of instructor
Acad Year 2024-2025: G (Fall)
Acad Year 2025-2026: Not offered
3-0-9 units

Explores the impact of nanoscale phenomena on macroscale transport of energy-carrying molecules, phonons, electrons, and excitons. Studies the effect of structural and energetic disorder, wave-like vs. particle-like transport, quantum and classical size effects, and quantum coherence. Emphasizes quantitative analysis, including the Boltzmann transport equation, Einstein relation, Wiedemann-Franz law, and Marcus electron transfer theory. Also addresses percolation theory and the connection to energy conversion technologies, such as solar cells, thermoelectrics, and LEDs. Students taking graduate version complete additional assignments.
W. A. Tisdale

10.52 Mechanics of Fluids
Prereq: 10.50
Acad Year 2024-2025: G (Fall)
Acad Year 2025-2026: Not offered
3-0-6 units

Advanced subject in fluid and continuum mechanics. Content includes kinematics, macroscopic balances for linear and angular momentum, the stress tensor, creeping flows and the lubrication approximation, the boundary layer approximation, linear stability theory, and some simple turbulent flows.
Staff

10.521 Design Principles in Mammalian Systems and Synthetic Biology
Subject meets with 10.321
Prereq: (7.05 and 18.03) or permission of instructor
Acad Year 2024-2025: G (Fall)
Acad Year 2025-2026: Not offered
3-0-6 units

Focuses on the layers of design, from molecular to large networks, in mammalian biology. Formally introduces concepts in the emerging fields of mammalian systems and synthetic biology, including engineering principles in neurobiology and stem cell biology. Exposes advanced students from quantitative backgrounds to problem-solving opportunities at the interface of molecular biology and engineering. Students taking graduate version complete additional assignments.
K. E. Galloway

10.524 Pharmaceutical Engineering
Subject meets with 10.424
Prereq: None
Acad Year 2024-2025: Not offered
Acad Year 2025-2026: G (Fall)
3-0-6 units

Presents engineering principles and unit operations involved in the manufacture of small molecules pharmaceuticals, from the isolation of purified active pharmaceutical ingredients (API) to the final production of drug product. Regulatory issues include quality by design and process analytical technologies of unit operations, such as crystallization, filtration, drying, milling, blending, granulation, tableting and coating. Also covers principles of formulation for solid dosage forms and parenteral drugs. Students taking graduate version complete additional assignments. Limited to 50.
A. S. Myerson

10.53[J] Advances in Biomanufacturing
Same subject as 7.548[J]
Subject meets with 7.458[J], 10.03[J]
Prereq: None
G (Spring; second half of term)
1-0-2 units

Seminar examines how biopharmaceuticals, an increasingly important class of pharmaceuticals, are manufactured. Topics range from fundamental bioprocesses to new technologies to the economics of biomanufacturing. Also covers the impact of globalization on regulation and quality approaches as well as supply chain integrity. Students taking graduate version complete additional assignments.
J. C. Love, A. Sinskey, S. Springs

10.531[J] Macromolecular Hydrodynamics
Same subject as 2.341[J]
Prereq: 2.25, 10.301, or permission of instructor
G (Spring)
Not offered regularly; consult department
3-0-6 units

See description under subject 2.341[J].
R. C. Armstrong, G. H. McKinley

10.534 Bioelectrochemistry
Prereq: None
Acad Year 2024-2025: G (Spring)
Acad Year 2025-2026: Not offered
3-0-6 units

Provides an overview of electrochemistry as it relates to biology, with an emphasis on electron transport in living systems. Primary literature used as a guide for discussion. Objective is to enable students to learn the fundamental principles of electrochemistry and electrochemical engineering applied to biological systems, explore the role of electron transfer in the natural world using examples from the primary literature, analyze recent work related to bioelectrochemistry, and develop an original research proposal based on course material. Topics include thermodynamics and transport processes in bioelectrical systems, electron transport chains in prokaryotes and eukaryotes, electroanalytical techniques for the evaluation of biological systems, and engineering bioenergetic systems.
A. L. Furst

10.535[J] Protein Engineering
Same subject as 20.535[J]
Prereq: 18.03 and (5.07[J] or 7.05)
G (Spring)
3-0-9 units

Introduces the field of protein engineering. Develops understanding of key biophysical chemistry concepts in protein structure/function and their applications. Explores formulation of simple kinetic, statistical, and transport models for directed evolution and drug biodistribution. Students read and critically discuss seminal papers from the literature.
K. D. Wittrup

10.536[J] Thermal Hydraulics in Power Technology
Same subject as 2.59[J], 22.313[J]
Prereq: 2.006, 10.302, 22.312, or permission of instructor
G (Fall)
3-2-7 units

See description under subject 22.313[J].
E. Baglietto, M. Bucci

10.537[J] Molecular, Cellular, and Tissue Biomechanics
Same subject as 2.798[J], 3.971[J], 6.4842[J], 20.410[J]
Subject meets with 2.797[J], 3.053[J], 6.4840[J], 20.310[J]
Prereq: Biology (GIR) and 18.03
G (Spring)
3-0-9 units

See description under subject 20.410[J].
M. Bathe, K. Ribbeck, P. T. So

10.538[J] Principles of Molecular Bioengineering
Same subject as 20.420[J]
Prereq: 7.06 and 18.03
G (Fall)
3-0-9 units

See description under subject 20.420[J].
A. Jasanoff, E. Fraenkel

10.539[J] Fields, Forces, and Flows in Biological Systems
Same subject as 2.795[J], 6.4832[J], 20.430[J]
Prereq: Permission of instructor
G (Fall)
3-0-9 units

See description under subject 20.430[J].
M. Bathe, A. J. Grodzinsky

10.540 Intracellular Dynamics
Prereq: 7.06, 10.302, 18.03, or permission of instructor
G (Spring)
Not offered regularly; consult department
3-0-9 units

Covers current models and descriptions of the internal cell dynamics of macromolecules due to reaction and transport. Two major areas will be explored: the process of gene expression, including protein-DNA interactions, chromatin dynamics, and the stochastic nature of gene expression; and cell signaling systems, especially those that lead to or rely on intracellular protein gradients. This class is intended for graduate students or advanced undergraduates with some background in cell biology, transport, and kinetics. An introductory class in probability is recommended.
N. Maheshri

10.542 Biochemical Engineering and Biomanufacturing Principles
Subject meets with 10.442
Prereq: (5.07[J], 10.37, and (7.012, 7.013, 7.014, 7.015, or 7.016)) or permission of instructor
G (Spring)
3-0-6 units

Explores the interactions of chemical engineering, biochemical engineering, and microbiology with particular emphasis on applications to bioprocess development. Examines mathematical representations of microbial systems, especially with regard to the kinetics of growth, death, and metabolism. Discusses the fundamentals of bioreactor design and operation, including continuous fermentation, mass transfer, and agitation. Examples encompass both enzyme and whole cell systems. Presents concepts in process development for microbial and animal cell cultures, with considerations towards production of biological products ranging from chiral specialty chemicals/pharmaceuticals to therapeutic proteins. Concludes with a discussion of aspects of cellular engineering and the role of molecular biology in addressing process development problems.
K. J. Prather

10.544 Metabolic and Cell Engineering
Prereq: 7.05, 10.302, and 18.03
G (Fall, Spring)
Not offered regularly; consult department
3-0-9 units

Presentation of a framework for quantitative understanding of cell functions as integrated molecular systems. Analysis of cell-level processes in terms of underlying molecular mechanisms based on thermodynamics, kinetics, mechanics, and transport principles, emphasizing an engineering, problem-oriented perspective. Objective is to rationalize target selection for genetic engineering and evaluate the physiology of recombinant cells. Topics include cell metabolism and energy production, transport across cell compartment barriers, protein synthesis and secretion, regulation of gene expression, transduction of signals from extracellular environment, cell proliferation, cell adhesion and migration.
Gr. Stephanopoulos

10.545 Fundamentals of Metabolic and Biochemical Engineering: Applications to Biomanufacturing
Subject meets with 10.345
Prereq: 5.07[J], 7.05, or permission of instructor
G (Spring)
Not offered regularly; consult department
3-0-9 units

Examines the fundamentals of cell and metabolic engineering for biocatalyst design and optimization, as well as biochemical engineering principles for bioreactor design and operation, and downstream processing. Presents applications of microbial processes for production of commodity and specialty chemicals and biofuels in addition to mammalian cell cultures for production of biopharmaceuticals. Students taking graduate version complete additional assignments.
Gr. Stephanopoulos

10.546[J] Statistical Thermodynamics
Same subject as 5.70[J]
Prereq: 5.601 or permission of instructor
G (Fall)
3-0-9 units

See description under subject 5.70[J].
J. Cao, B. Zhang

10.547[J] Principles and Practice of Drug Development
Same subject as 15.136[J], HST.920[J], IDS.620[J]
Prereq: Permission of instructor
G (Fall)
3-0-6 units

See description under subject 15.136[J].
S. Finkelstein, A. J. Sinskey, R. Rubin

10.548[J] Tumor Microenvironment and Immuno-Oncology: A Systems Biology Approach
Same subject as HST.525[J]
Prereq: None
Acad Year 2024-2025: G (Fall)
Acad Year 2025-2026: Not offered
2-0-4 units

See description under subject HST.525[J].
R. K. Jain, L. Munn

10.55 Colloid and Surfactant Science
Prereq: Permission of instructor
G (Fall)
Not offered regularly; consult department
3-0-6 units

Introduces fundamental and applied aspects of colloidal dispersions, where the typical particle size is less than a micrometer. Discusses the characterization and unique behavior of colloidal dispersions, including their large surface-to-volume ratio, tendency to sediment in gravitational and centrifugal fields, diffusion characteristics, and ability to generate osmotic pressure and establish Donnan equilibrium. Covers the fundamentals of attractive van der Waals forces and repulsive electrostatic forces. Presents an in-depth discussion of electrostatic and polymer-induced colloid stabilization, including the DLVO theory of colloid stability. Presents an introductory discussion of surfactant physical chemistry.
D. Blankschtein

10.551 Systems Engineering
Prereq: 10.213, 10.302, and 10.37
G (Spring)
3-0-6 units

Introduction to the elements of systems engineering. Special attention devoted to those tools that help students structure and solve complex problems. Illustrative examples drawn from a broad variety of chemical engineering topics, including product development and design, process development and design, experimental and theoretical analysis of physico-chemical process, analysis of process operations.
R. D. Braatz, P. I. Barton

10.552 Modern Control Design
Subject meets with 10.352
Prereq: None
G (Fall)
Not offered regularly; consult department
3-0-9 units

Covers modern methods for dynamical systems analysis, state estimation, controller design, and related topics. Uses example applications to demonstrate Lyapunov and linear matrix inequality-based methods that explicitly address actuator constraints, nonlinearities, and model uncertainties. Students taking graduate version complete additional assignments. Limited to 30.
R. D. Braatz

10.553 Model Predictive Control
Subject meets with 10.353
Prereq: None
G (Fall)
Not offered regularly; consult department
3-0-9 units

Provides an introduction to the multivariable control of dynamical systems with constraints on manipulated, state, and output variables. Covers multiple mathematical formulations that are popular in academia and industry, including dynamic matrix control and state-space model predictive control of uncertain, nonlinear, and large-scale systems. Uses numerous real industrial processes as examples. Students taking graduate version complete additional assignments.
R. D. Braatz

10.554[J] Process Data Analytics
Same subject as 2.884[J]
Subject meets with 2.874[J], 10.354[J]
Prereq: None
Acad Year 2024-2025: G (Fall)
Acad Year 2025-2026: Not offered
4-0-8 units

Provides an introduction to data analytics for manufacturing processes. Topics include chemometrics, discriminant analysis, hyperspectral imaging, machine learning, big data, Bayesian methods, experimental design, feature spaces, and pattern recognition as relevant to manufacturing process applications (e.g., output estimation, process control, and fault detection, identification and diagnosis). Students taking graduate version complete additional assignments.
R. D. Braatz, B. Anthony

10.555[J] Bioinformatics: Principles, Methods and Applications
Same subject as HST.940[J]
Prereq: Permission of instructor
G (Spring)
Not offered regularly; consult department
3-0-9 units

Introduction to bioinformatics, the collection of principles and computational methods used to upgrade the information content of biological data generated by genome sequencing, proteomics, and cell-wide physiological measurements of gene expression and metabolic fluxes. Fundamentals from systems theory presented to define modeling philosophies and simulation methodologies for the integration of genomic and physiological data in the analysis of complex biological processes. Various computational methods address a broad spectrum of problems in functional genomics and cell physiology. Application of bioinformatics to metabolic engineering, drug design, and biotechnology also discussed.
Gr. Stephanopoulos, I. Rigoutsos

10.557 Mixed-integer and Nonconvex Optimization
Prereq: 10.34 or 15.053
Acad Year 2024-2025: G (Spring)
Acad Year 2025-2026: Not offered
3-0-9 units

Presents the theory and practice of deterministic algorithms for locating the global solution of NP-hard optimization problems. Recurring themes and methods are convex relaxations, branch-and-bound, cutting planes, outer approximation and primal-relaxed dual approaches. Emphasis is placed on the connections between methods. These methods will be applied and illustrated in the development of algorithms for mixed-integer linear programs, mixed-integer convex programs, nonconvex programs, mixed-integer nonconvex programs, and programs with ordinary differential equations embedded. The broad range of engineering applications for these optimization formulations will also be emphasized. Students will be assessed on homework and a term project for which examples from own research are encouraged.
P. I. Barton

10.56 Advanced Topics in Surfactant Science
Prereq: Permission of instructor
G (Spring)
Not offered regularly; consult department
3-0-6 units

Introduces fundamental advances and practical aspects of surfactant self-assembly in aqueous media. In-depth discussion of surfactant micellization, including statistical-thermodynamics of micellar solutions, models of micellar growth, molecular models for the free energy of micellization, and geometric packing theories. Presents an introductory examination of mixed micelle and vesicle formation, polymer-surfactant complexation, biomolecule-surfactant interactions, and micellar-assisted solubilization. Discusses molecular dynamics simulations of self-assembling systems. Covers recent advances in surfactant-induced dispersion and stabilization of colloidal particles (e.g., carbon nanotubes and graphene) in aqueous media. Examines surfactant applications in consumer products, environmental and biological separations, enhanced oil recovery using surfactant flooding, mitigation of skin irritation induced by surfactant-containing cosmetic products, and enhanced transdermal drug delivery using ultrasound and surfactants.
D. Blankschtein

10.560 Structure and Properties of Polymers
Prereq: 10.213 or permission of instructor
G (Spring)
Not offered regularly; consult department
3-0-6 units

Review of polymer molecular structure and bulk morphology; survey of molecular and morphological influence on bulk physical properties including non-Newtonian flow, macromolecular diffusion, gas transport in polymers, electrical and optical properties, solid-state deformation, and toughness. Case studies for product design.
R. E. Cohen

10.562[J] Pioneering Technologies for Interrogating Complex Biological Systems
Same subject as 9.271[J], HST.562[J]
Prereq: None
G (Spring)
3-0-9 units

See description under subject HST.562[J]. Limited to 15.
K. Chung

10.566 Structure of Soft Matter
Subject meets with 10.466
Prereq: 5.60
G (Fall)
Not offered regularly; consult department
3-0-6 units

Provides an introduction to the basic thermodynamic language used for describing the structure of materials, followed by a survey of the scattering, microscopy and spectroscopic techniques for structure and morphology characterization. Applies these concepts to a series of case studies illustrating the diverse structures formed in soft materials and the common length, time and energy scales that unify this field. For students interested in studying polymer science, colloid science, nanotechnology, biomaterials, and liquid crystals. Students taking graduate version complete additional assignments.
B. D. Olsen

10.568 Physical Chemistry of Polymers
Subject meets with 3.063, 3.942
Prereq: Prereq: 10.213, 10.40, or (5.601 AND 5.602)
Acad Year 2024-2025: G (Fall)
Acad Year 2025-2026: Not offered
3-0-9 units

Introduction to polymer science from a molecular perspective. Covers topics in macromolecular confirmation and spatial extent, polymer solution thermodynamics and the theta state, linear viscoelasticity, rubber elasticity, and the thermodynamics and kinetics of formation of glasses and semicrystalline solids. Also provides a basic introduction to dynamics of macromolecules in solutions and melts, with entanglements. Presents methods for characterizing the molecular structure of polymers.
G. C. Rutledge, A. Alexander-Katz

10.569 Synthesis of Polymers
Prereq: 5.12
G (Fall)
3-0-6 units

Studies synthesis of polymeric materials, emphasizing interrelationships of chemical pathways, process conditions, and microarchitecture of molecules produced. Chemical pathways include traditional approaches such as anionic, radical condensation, and ring-opening polymerizations. New techniques, including stable free radicals and atom transfer free radicals, new catalytic approaches to well-defined architectures, and polymer functionalization in bulk and at surfaces. Process conditions include bulk, solution, emulsion, suspension, gas phase, and batch vs continuous fluidized bed. Microarchitecture includes tacticity, molecular-weight distribution, sequence distributions in copolymers, errors in chains such as branches, head-to-head addition, and peroxide incorporation.
Z. Smith

10.571[J] Atmospheric Physics and Chemistry
Same subject as 12.806[J]
Subject meets with 12.306
Prereq: (18.075 and (5.60 or 5.61)) or permission of instructor
G (Spring)
3-0-9 units

See description under subject 12.806[J].
R. G. Prinn

10.580 Solid-State Surface Science
Prereq: 10.213
G (Fall)
Not offered regularly; consult department
3-0-6 units

Structural, chemical, and electronic properties of solids and solid surfaces. Analytical tools used to characterize surfaces including Auger and photoelectron spectroscopies and electron diffraction techniques. Surface thermodynamics and kinetics including adsorption-desorption, catalytic properties, and sputtering processes. Applications to microelectronics, optical materials, and catalysis.
K. K. Gleason

10.585 Engineering Nanotechnology
Prereq: 10.213, 10.302, or permission of instructor
G (Fall)
3-0-9 units

Review of fundamental concepts of energy, mass and electron transport in materials confined or geometrically patterned at the nanoscale, where departures from classical laws are dominant. Specific applications to contemporary engineering challenges are discussed including problems in energy, biology, medicine, electronics, and material design.
M. Strano

10.586 Crystallization Science and Technology
Prereq: 10.213
Acad Year 2024-2025: G (Fall)
Acad Year 2025-2026: Not offered
3-0-6 units

Studies the nucleation and growth of crystals from a melt or a liquid solution and their important role in a wide range of applications, including pharmaceuticals, proteins, and semiconductor materials. Provides background information and covers topics needed to understand, perform experiments, construct and simulate mechanistic models, and design, monitor, and control crystallization processes. Limited to 30.
A. S. Myerson

10.591 Case Studies in Bioengineering
Prereq: Biology (GIR) or permission of instructor
G (Spring)
Not offered regularly; consult department
3-0-6 units

Analysis and discussion of recent research in areas of bioengineering, including drug delivery, protein and tissue engineering, physiological transport, stem cell technology, and quantitative immunology by senior investigators in the Boston area. Students will read and critique papers, then have discussions with authors about their work.
C. K. Colton

10.595 Molecular Design and Bioprocess Development of Immunotherapies
Subject meets with 10.495
Prereq: Permission of instructor
Acad Year 2024-2025: Not offered
Acad Year 2025-2026: G (Fall)
3-0-6 units

Examines challenges and opportunities for applying chemical engineering principles to address the growing global burden of infectious disease, including drug-resistant strains and neglected pathogens. Topics include a historical overview of vaccines and immunotherapies, the molecular design considerations for new immunotherapies and adjuvants, the economic challenges for process development and manufacturing of immunotherapies, and new technologies for designing and assessing therapies. Case studies to cover topics for specific diseases. Students taking graduate version complete additional assignments.
J. C. Love

10.600[J] Dimensions of Geoengineering
Same subject as 1.850[J], 5.000[J], 11.388[J], 12.884[J], 15.036[J], 16.645[J]
Prereq: None
G (Fall; first half of term)
Not offered regularly; consult department
2-0-4 units

See description under subject 5.000[J]. Limited to 100.
J. Deutch, M. Zuber

10.606 Picturing Science and Engineering
Prereq: None
G (Spring; second half of term)
Not offered regularly; consult department
1-2-2 units

Provides instruction in best practices for creating more effective graphics and photographs to support and communicate research in science and engineering. Discusses in depth specific examples from a range of scientific contexts, such as journal articles, presentations, grant submissions, and cover art. Topics include graphics for figures depicting form and structure, process, and change over time. Prepares students to create effective graphics for submissions to existing journals and calls attention to the future of published graphics with the advent of interactivity. Limited to 10.
F. Frankel

10.621[J] Energy Systems for Climate Change Mitigation
Same subject as 1.670[J], IDS.521[J]
Subject meets with 1.067[J], 10.421[J], IDS.065[J]
Prereq: Permission of instructor
G (Fall)
3-0-9 units

See description under subject IDS.521[J].
J. Trancik

10.625[J] Electrochemical Energy Conversion and Storage: Fundamentals, Materials and Applications
Same subject as 2.625[J]
Prereq: 2.005, 3.046, 3.53, 10.40, (2.051 and 2.06), or permission of instructor
G (Fall)
Not offered regularly; consult department
4-0-8 units

See description under subject 2.625[J].
Y. Shao-Horn

10.626 Electrochemical Energy Systems
Subject meets with 10.426
Prereq: 10.50 or permission of instructor
G (Fall)
3-0-9 units

Introduces electrochemical energy systems from the perspective of thermodynamics, kinetics, and transport. Surveys analysis and design of electrochemical reactions and processes by integrating chemical engineering fundamentals with knowledge from diverse fields, including chemistry, electrical engineering, and materials science. Includes applications to fuel cells, electrolyzers, and batteries. Students taking graduate version complete additional assignments.
M. Z. Bazant

10.631 Structural Theories of Polymer Fluid Mechanics
Prereq: 10.301
G (Spring)
Not offered regularly; consult department
3-0-6 units

Structural and molecular models for polymeric liquids. Nonequilibrium properties are emphasized. Elementary kinetic theory of polymer solutions. General phase space kinetic for polymer melts and solutions. Network theories. Interrelations between structure and rheological properties.
R. C. Armstrong

10.637[J] Computational Chemistry
Same subject as 5.698[J]
Subject meets with 5.697[J], 10.437[J]
Prereq: Permission of instructor
Acad Year 2024-2025: Not offered
Acad Year 2025-2026: G (Fall)
3-0-9 units

Addresses both the theory and application of first-principles computer simulations methods (i.e., quantum, chemical, or electronic structure), including Hartree-Fock theory, density functional theory, and correlated wavefunction methods. Covers enhanced sampling, ab initio molecular dynamics, and transition-path-finding approaches as well as errors and accuracy in total and free energies. Discusses applications such as the study and prediction of properties of chemical systems, including heterogeneous, molecular, and biological catalysts (enzymes), and physical properties of materials. Students taking graduate version complete additional assignments. Limited to 35; no listeners.
H. J. Kulik

10.643[J] Future Medicine: Drug Delivery, Therapeutics, and Diagnostics
Same subject as HST.526[J]
Subject meets with 10.443
Prereq: 5.12 or permission of instructor
G (Spring)
Not offered regularly; consult department
3-0-6 units

Aims to describe the direction and future of medical technology. Introduces pharmaceutics, pharmacology, and conventional medical devices, then transitions to drug delivery systems, mechanical/electric-based and biological/cell-based therapies, and sensors. Covers nano- and micro drug delivery systems, including polymer-drug conjugates, protein therapeutics, liposomes and polymer nanoparticles, viral and non-viral genetic therapy, and tissue engineering. Previous coursework in cell biology and organic chemistry recommended. Students taking graduate version complete additional assignments. Limited to 40.
D. G. Anderson

10.65 Chemical Reactor Engineering
Prereq: 10.37 or permission of instructor
G (Spring)
4-0-8 units

Fundamentals of chemically reacting systems with emphasis on synthesis of chemical kinetics and transport phenomena. Topics include kinetics of gas, liquid, and surface reactions; quantum chemistry; transition state theory; surface adsorption, diffusion, and desorption processes; mechanism and kinetics of biological processes; mechanism formulation and sensitivity analysis. Reactor topics include nonideal flow reactors, residence time distribution and dispersion models; multiphase reaction systems; nonlinear reactor phenomena. Examples are drawn from different applications, including heterogeneous catalysis, polymerization, combustion, biochemical systems, and materials processing.
M. Strano, G. Stephanopoulos

10.652[J] Kinetics of Chemical Reactions
Same subject as 5.68[J]
Prereq: 5.62, 10.37, or 10.65
Acad Year 2024-2025: Not offered
Acad Year 2025-2026: G (Fall)
3-0-6 units

See description under subject 5.68[J].
W. H. Green

10.668[J] Statistical Mechanics of Polymers
Same subject as 3.941[J]
Prereq: 10.568 or permission of instructor
Acad Year 2024-2025: Not offered
Acad Year 2025-2026: G (Fall)
3-0-9 units

Concepts of statistical mechanics and thermodynamics applied to macromolecules: polymer conformations in melts, solutions, and gels; Rotational Isomeric State theory, Markov processes and molecular simulation methods applied to polymers; incompatibility and segregation in incompressible and compressible systems; molecular theory of viscoelasticity; relation to scattering and experimental measurements.
G. C. Rutledge, A. Alexander-Katz

10.677 Topics in Applied Microfluidics
Prereq: 10.301 or permission of instructor
G (Fall)
3-0-6 units

Provides an introduction to the field of microfluidics. Reviews fundamental concepts in transport phenomena and dimensional analysis, focusing on new phenomena which arise at small scales. Discusses current applications, with an emphasis on the contributions engineers bring to the field. Local and visiting experts in the field discuss their work. Limited to 30.
P. Doyle

10.689 Concepts in Modern Heterogeneous Catalysis
Subject meets with 10.489
Prereq: 10.302 and 10.37
G (Spring)
Not offered regularly; consult department
3-0-6 units

Explores topics in the design and implementation of heterogeneous catalysts for chemical transformations. Emphasizes use of catalysis for environmentally benign and sustainable chemical processes. Lectures address concepts in catalyst preparation, catalyst characterization, quantum chemical calculations, and microkinetic analysis of catalytic processes. Shows how experimental and theoretical approaches can illustrate important reactive intermediates and transition states involved in chemical reaction pathways, and uses that information to help identify possible new catalysts that may facilitate reactions of interest. Draws examples from current relevant topics in catalysis. Includes a group project in which students investigate a specific topic in greater depth. Students taking graduate version complete additional assignments.
Y. Roman

10.7003[J] Applied Molecular Biology Laboratory
Same subject as 7.003[J]
Prereq: 7.002
U (Fall, Spring)
2-7-3 units. Partial Lab

See description under subject 7.003[J]. Enrollment limited; admittance may be controlled by lottery.
Fall: E. Calo, K. Knouse. Spring: L. Case, H. Moura Silva

10.792[J] Global Operations Leadership Seminar
Same subject as 2.890[J], 15.792[J], 16.985[J]
Prereq: None
G (Fall, Spring)
2-0-0 units
Can be repeated for credit.

See description under subject 15.792[J]. Preference to LGO students.
T. Roemer

10.801 Project Management and Problem Solving in Academia and Industry
Prereq: None
G (IAP)
3-0-3 units

Teaches both soft and hard skills to foster student success through one-month team projects, as part of the Master of Science in Chemical Engineering Practice (M.S.CEP) program. The same skills are expected to be valuable for problem-solving in both academic and industrial settings at large. Themes to be covered include career development, project management, leadership, project economics, techniques for problem solving, literature search, safety, professional behavior, and time management. Students participate in activities and discussions during class time, study preparatory and review materials on MITx and complete active-learning assessments between meetings, and complete a quiz at the end of the course. Enrollment will be limited to students in the School of Chemical Engineering Practice.
T. A. Hatton

10.805[J] Technology, Law, and the Working Environment
Same subject as IDS.436[J]
Subject meets with 1.802[J], 1.812[J], 11.022[J], 11.631[J], IDS.061[J], IDS.541[J]
Prereq: Permission of instructor
G (Spring)
Not offered regularly; consult department
3-0-6 units

See description under subject IDS.436[J].
N. A. Ashford, C. C. Caldart

10.806 Management in Engineering
Engineering School-Wide Elective Subject.
Offered under: 2.96, 6.9360, 10.806, 16.653
Prereq: None
U (Fall)
3-1-8 units

See description under subject 2.96. Restricted to juniors and seniors.
H. S. Marcus, J.-H. Chun

10.807[J] Innovation Teams
Same subject as 2.907[J], 15.371[J]
Prereq: None
G (Fall)
4-4-4 units

Introduces skills and capabilities for real-world problem solving to take technology from lab to societal impact: technical and functional exploration, opportunity discovery, market understanding, value economics, scale-up, intellectual property, and communicating/working for impact across disciplines. Students work in multidisciplinary teams formed around MIT research breakthroughs, with extensive in-class coaching and guidance from faculty, lab members, and select mentors. Follows a structured approach to innovating in which everything is a variable and the product, technology, and opportunities for new ventures can be seen as an act of synthesis. Teams gather evidence that permits a fact-based iteration across multiple application domains, markets, functionalities, technologies, and products, leading to a recommendation that maps a space of opportunity and includes actionable next steps to evolve the market and technology.
L. Perez-Breva, D. Hart

10.817[J] Atmospheric Chemistry
Same subject as 1.84[J], 12.807[J]
Prereq: 5.601 and 5.602
G (Fall)
3-0-9 units

See description under subject 1.84[J].
J. H. Kroll

School of Chemical Engineering Practice

10.80 (10.82, 10.84, 10.86) School of Chemical Engineering Practice -- Technical Accomplishment
Prereq: None
G (Fall, Spring, Summer)
0-6-0 units

Conducted at industrial field stations of the School of Chemical Engineering Practice. Group problem assignments include process development design, simulation and control, technical service, and new-product development. Grading based on technical accomplishment. Credit granted in lieu of master's thesis. See departmental descripton on School of Chemical Engineering Practice for details. Enrollment limited and subject to plant availability.
T. A. Hatton

10.81 (10.83, 10.85, 10.87) School of Chemical Engineering Practice -- Communication Skills and Human Relations
Prereq: None
G (Fall, Spring, Summer)
0-6-0 units

Conducted at industrial field stations of the School of Chemical Engineering Practice. Group problem assignments include process development, design, simulation and control, technical service, and new-product development. Grading based on communication skills and human relations in group assignments. Credit granted in lieu of master's thesis; see departmental description on School of Chemical Engineering Practice for details. Enrollment limited and subject to plant availability.
T. A. Hatton

General

10.90 Independent Research Problem
Prereq: Permission of instructor
G (Fall, Spring, Summer)
Units arranged
Can be repeated for credit.

For special and graduate students who wish to carry out some minor investigation in a particular field. Subject and hours to fit individual requirements.
P. S. Doyle

10.910 Independent Research Problem
Prereq: None
U (Fall, IAP, Spring, Summer)
Units arranged
Can be repeated for credit.

For undergraduate students who wish to carry out a special investigation in a particular field. Topic and hours arranged.
B. S. Johnston

10.911 Independent Research Problem
Prereq: None
U (Fall, IAP, Spring, Summer)
Units arranged [P/D/F]
Can be repeated for credit.

For undergraduate students who wish to carry out a special investigation in a particular field. Topic and hours arranged.
B. S. Johnston

10.912 Practical Internship in Chemical Engineering
Prereq: None
U (Fall, IAP, Spring, Summer)
0-1-0 units
Can be repeated for credit.

Provides academic credit for professional experiences in chemical engineering at external facilities, such as companies or laboratories. At the end of the internship, students must submit a report that describes the experience, details their accomplishments, and synthesizes the perspectives, knowledge, and skills to be carried forward into the rest of their studies.
B. S. Johnston

10.951 Seminar in Biological Systems
Prereq: Permission of instructor
G (Fall, IAP, Spring, Summer)
2-0-4 units
Can be repeated for credit.

Students, postdocs, and visitors to present their work on design, construction, and characterization of biological systems expanding on topics in synthetic biology, molecular systems biology, and cellular reprogramming.
K. E. Galloway

10.952 Seminar in Bioelectrochemical Engineering
Prereq: Permission of instructor
G (Fall, IAP, Spring, Summer)
2-0-4 units
Can be repeated for credit.

Students, postdocs and visitors present and discuss their research in bioelectrochemistry. Specific topics include electrochemical platform design for diagnostics and screening tools, fundamental studies of metalloproteins and electron transfer-proficient microbes, materials for bioelectronics, and *in vitro* disease models.
A. L. Furst

10.953 Seminar in Heterogeneous Catalysis
Prereq: None
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Students present their research to other students and staff. Research topics include heterogeneous catalysis, design of catalytic materials, biomass conversion, biofuels, and CO_2 utilization.
Y. Roman

10.954 Seminar in Applied Optical Spectroscopy
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Research seminars given by students, postdocs, and visitors. Topics covered include applied optical spectroscopy and imaging, with particular emphasis on nanomaterials and how they relate to alternative energy technologies.
W. A. Tisdale

10.955 Seminar in Electrochemical Engineering
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Designed to allow students to present and discuss their research in the area of electrochemical engineering with a particular emphasis on energy storage and conversion (e.g., batteries, fuel cells, electroreactors). Specific topics include active materials design, electroanalytical platform development, and integration of electrochemical and imaging techniques.
F. R. Brushett

10.956 Seminar in Atomistic Simulation
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Seminar allows students to present their research to other students and staff. The research topics include electronic structure theory, computational chemistry techniques, and density functional theory with a focus on applications to catalysis and materials science.
H. J. Kulik

10.957 Seminar in Bioengineering Technology
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Research seminars presented by students and guest speakers on emerging biotechnologies.
K. Chung

10.958 Seminar in the Fluid Mechanics and Self-assembly of Soft Matter
Prereq: Permission of instructor
G (Fall, Spring)
Not offered regularly; consult department
2-0-4 units
Can be repeated for credit.

Covers topics related to low Reynolds number hydrodynamics and the statistical physics of particulate media. Specifics include the kinetics of phase transitions in soft matter and the time-varying deformation of colloidal dispersions, glasses and gels.
J. W. Swan

10.960[J] Seminar in Polymers and Soft Matter
Same subject as 3.903[J]
Prereq: None
G (Fall, Spring)
2-0-0 units
Can be repeated for credit.

A series of seminars covering a broad spectrum of topics in polymer science and engineering, featuring both on- and off-campus speakers.
A. Alexander-Katz, R. E. Cohen, D. Irvine

10.961 Seminar in Advanced Air Pollution Research
Prereq: Permission of instructor
G (Fall, Spring)
Not offered regularly; consult department
2-0-4 units
Can be repeated for credit.

Research seminars, presented by students engaged in thesis work in the field of air pollution. Particular emphasis given to atmospheric chemistry, mathematical modeling, and policy analysis.
G. J. McRae

10.962 Seminar in Molecular Cell Engineering
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Weekly seminar with discussion of ongoing research and relevant literature by graduate students, postdoctoral fellows, and visiting scientists on issues at the interface of chemical engineering with molecular cell biology. Emphasis is on quantitative aspects of physicochemical mechanisms involved in receptor/ligand interactions, receptor signal transduction processes, receptor-mediated cell behavioral responses, and applications of these in biotechnology and medicine.
D. A. Lauffenburger

10.963 Seminar in Computer-Assisted Molecular Discovery
Prereq: Permission of instructor
G (Fall, IAP, Spring, Summer)
2-0-4 units
Can be repeated for credit.

Allows students to present their research and literature reviews to other students and staff. Topics include the use of automation and computational methods for understanding the biological, chemical, and physical properties of molecular structures, as well as the design of new functional molecules and the synthetic processes to produce them.
C. W. Coley

10.964 Seminar on Transport Theory
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Research seminars presented by students and guest speakers on mathematical modeling of transport phenomena, focusing on electrochemical systems, electrokinetics, and microfluidics.
M. Z. Bazant

10.965 Seminar in Biosystems Engineering
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Advanced topics on the state-of-the-art in design and implementation of analytical processes for biological systems, including single-cell analysis, micro/nanotechnologies, systems biology, biomanufacturing, and process engineering. Seminars and discussions guided by the research interests of participating graduate students, postdoctoral associates, faculty, and visiting lecturers.
J. C. Love

10.966 Seminar in Drug Delivery, Biomaterials, and Tissue Engineering
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Focuses on presentations by students and staff on current research in the area of drug delivery, biomaterials, and tissue engineering. Includes topics such as nanotherapeutics, intracellular delivery, and therapies for diabetes.
D. G. Anderson

10.967 Seminar in Protein-Polymer Materials Engineering
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Research seminar covers topics on protein-based polymeric materials. Specific topics include bioelectronic materials, protein-polymer hybrids, and nanostructured proteins and polymers.
B. D. Olsen

10.968 Seminar in Biomolecular Engineering
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Covers research progress in the area of design, testing and mechanistic investigation of novel molecular systems for biotechnological applications.
H. D. Sikes

10.969 Molecular Engineering Seminar
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Seminar allows students to present their research to other students and staff. Research topics include molecular simulations techniques and applications, and molecular engineering of pharmaceutical and biopharmaceutical processes and formulations.
B. L. Trout

10.970 Seminar in Molecular Computation
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Seminar allows students to present their research to other students and staff. The research topics include computational chemistry techniques, kinetics, and catalysis. Focus is on molecular-level understanding of chemical change.
W. H. Green

10.971 Seminar in Fluid Mechanics and Transport Phenomena
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Seminar series on current research on Newtonian and non-Newtonian fluid mechanics and transport phenomena, and applications to materials processing. Seminars given by guest speakers and research students.
P. S. Doyle, G. H. McKinley

10.972 Biochemical Engineering Research Seminar
Prereq: Permission of instructor
G (Fall, Spring)
Not offered regularly; consult department
2-0-4 units
Can be repeated for credit.

Seminar allows students to present their research programs to other students and staff. The research topics include fermentation and enzyme technology, mammalian and animal cell cultivation, and biological product separation.
D. I. C. Wang, C. L. Cooney

10.973 Bioengineering
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Seminar covering topics related to current research in the application of chemical engineering principles to biomedical science and biotechnology.
C. K. Colton

10.974 Seminar in Chemical Engineering Nanotechnology
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Seminar covering topics related to current research in the application of chemical engineering principles to nanotechnology. Limited to 30.
M. S. Strano

10.975 Seminar in Polymer Science and Engineering
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Research seminars, presented by students engaged in thesis work in the field of polymers and by visiting lecturers from industry and academia.
P. T. Hammond, G. C. Rutledge

10.976 Process Design, Operations, and Control
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Seminars on the state of the art in design, operations, and control of processing systems, with emphasis on computer-based tools. Discussions guided by the research interests of participating students. Topics include mathematical and numerical techniques, representational methodologies, and software development.
P. I. Barton

10.977 Seminar in Electrocatalysis
Prereq: Permission of instructor
G (Fall, Spring)
Not offered regularly; consult department
2-0-4 units
Can be repeated for credit.

Seminar held every week, with presentations by graduate students and postdoctoral researchers on topics related to the molecular engineering of electrocatalysts. Emphasis on correlating atomic-level understanding of surfaces, their interactions with adsorbates, and the resulting impact on catalytic mechanisms.
K. Manthiram

10.978 Seminar in Advanced Materials for Energy Applications
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Students, postdocs, and visitors to present their work on synthesis, design, and characterization of polymeric and inorganic materials for applications related to membrane and adsorption-based separations.
Z. P. Smith

10.979 Seminar in Biological Soft Matter
Prereq: Permission of instructor
G (Fall, IAP, Spring, Summer)
2-0-4 units
Can be repeated for credit.

Students, postdocs, and visitors present their work on understanding and designing soft materials and complex fluids related to human health and medical applications. Both experimental and modeling approaches are discussed, covering topics such as macromolecular transport, microhydrodynamics, biomechanics, microfluidics, and microphysiological systems.
Q. M. Qi

10.981 Seminar in Colloid and Interface Science
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Review of current topics in colloid and interface science. Topics include statistical mechanics and thermodynamics of micellar solutions, self-assembling systems, and microemulsions; solubilization of simple ions, amino acids, and proteins in reversed micelles; enzymatic reactions in reversed micelles; phase equilibria in colloidal systems; interfacial phenomena in colloidal systems; biomedical aspects of colloidal systems.
D. Blankschtein

10.982 Seminar in Experimental Colloid and Surface Chemistry
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

In-depth discussion of fundamental physical relationships underlying techniques commonly used in the study of colloids and surfaces with a focus on recent advances and experimental applications. Topics have included the application of steady-state and time-resolved fluorescence spectroscopies, infrared spectroscopy, and scanning probe microscopies.
T. A. Hatton

10.983 Reactive Processing and Microfabricated Chemical Systems
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Advanced topics in synthesis of materials through processes involving transport phenomena and chemical reactions. Chemical vapor deposition, modeling, and experimental approaches to kinetics of gas phase and surface reactions, transport phenomena in complex systems, materials synthesis, and materials characterization. Design fabrication and applications of microfabricated chemical systems. Seminars by graduate students, postdoctoral associates, participating faculty, and visiting lecturers.
K. F. Jensen

10.984 Biomedical Applications of Chemical Engineering
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Weekly seminar with lectures on current research by graduate students, postdoctoral fellows, and visiting scientists on topics related to biomedical applications of chemical engineering. Specific topics include polymeric controlled release technology, extracorporal reactor design, biomedical polymers, bioengineering aspects of pharmaceuticals, and biomaterials/tissue and cell interactions.
R. S. Langer

10.985 Advanced Manufacturing Seminar
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Focuses on the state of the art in the systems engineering of materials products and materials manufacturing processes. Addresses topics such as pharmaceuticals manufacturing, polymeric drug delivery systems, and nano- and microstructured materials. Discussions guided by the research interests of participating students. Includes techniques from applied mathematics and numerical methods, multiscale systems analysis, and control theory.
R. D. Braatz

10.986 Seminar in Energy Systems
Prereq: Permission of instructor
G (Fall, IAP, Spring, Summer)
2-0-4 units
Can be repeated for credit.

Seminar series on current research on energy systems modeling and analysis. Seminars given by guest speakers and research students.
R. C. Armstrong

10.987 Solid Thin Films and Interfaces
Prereq: Permission of instructor
G (Fall, Spring)
Not offered regularly; consult department
2-0-4 units
Can be repeated for credit.

Current research topics and fundamental issues relating to the deposition and properties of solid thin films and interfaces. Emphasis on applying analytical techniques, such as solid-state NMR, to explore the thermodynamics and kinetics of growth, defect formation, and structural modification incurred during film growth and post processing.
K. K. Gleason

10.988 Seminar in Immune Engineering
Prereq: Permission of instructor
G (Fall, IAP, Spring, Summer)
2-0-4 units
Can be repeated for credit.

Students, postdocs, and visitors present their work on the discovery of protein drugs and the engineering of immune responses to advance human health and enhance fundamental knowledge of immune systems. Experimental and computational methods are discussed, covering topics such as antibodies, T cell receptors, vaccines, protein therapeutics, infectious diseases, autoimmune mechanisms, and cancer treatments.
B. DeKosky

10.989 Seminar in Biotechnology
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Research seminars, presented by graduate students and visitors from industry and academia, covering a broad range of topics of current interest in biotechnology. Discussion focuses on generic questions with potential biotechnological applications and the quest for solutions through a coordinated interdisciplinary approach.
Gr. Stephanopoulos

10.990 Introduction to Chemical Engineering Research
Prereq: None
G (Fall)
2-4-0 units

Introduction to research in chemical engineering by faculty of chemical engineering department. Focus is on recent developments and research projects available to new graduate students.
P. T. Hammond

10.991 Seminar in Chemical Engineering
Prereq: Permission of instructor
G (Fall)
2-0-4 units
Can be repeated for credit.

For students working on doctoral theses.
P. T. Hammond

10.992 Seminar in Chemical Engineering
Prereq: Permission of instructor
G (Spring)
2-0-4 units
Can be repeated for credit.

For students working on doctoral theses.
K. F. Jensen

10.994 Molecular Bioengineering
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Presentations and discussion by graduate students, postdoctoral fellows, and visiting scientists of current literature and research on the engineering of protein biopharmaceuticals. Topics include combinatorial library construction and screening strategies, antibody engineering, gene therapy, cytokine engineering, and immunotherapy engineering strategies.
K. D. Wittrup

10.995 Cellular and Metabolic Engineering
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Graduate students, postdoctoral fellows, visiting scientists, and guest industrial practitioners to present their own research and highlight important advances from the literature in biochemical and bioprocess engineering. Topics of interest include metabolic engineering, novel microbial pathway design and optimization, synthetic biology, and applications of molecular biology to bioprocess development.
K. J. Prather

10.997 Theoretical and Computational Immunology Seminar
Prereq: Permission of instructor
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Presentations and discussions of current literature and research in theoretical and computational immunology. Topics include T cell biology, cell-cell recognition in immunology, polymers and membranes, and statistical mechanics.
A. K. Chakraborty

10.998 Seminar in Crystallization Science and Technology
Prereq: None
G (Fall, Spring)
2-0-4 units
Can be repeated for credit.

Focuses on current topics related to crystallization science and technology in the chemical, pharmaceutical and food industries. Discusses fundamental work on nucleation, polymorphism, impurity crystal interactions and nano-crystal formation, along with industrial applications of crystallization.
A. S. Myerson

10.C01[J] Machine Learning for Molecular Engineering
Same subject as 3.C01[J], 20.C01[J]
Subject meets with 3.C51[J], 7.C01, 7.C51, 10.C51[J], 20.C51[J]
Prereq: Calculus II (GIR), 6.100A, and 6.C01
U (Spring)
2-0-4 units

See description under subject 3.C01[J].
R. Gomez-Bombarelli, C. Coley, E. Fraenkel

10.C51[J] Machine Learning for Molecular Engineering
Same subject as 3.C51[J], 20.C51[J]
Subject meets with 3.C01[J], 7.C01, 7.C51, 10.C01[J], 20.C01[J]
Prereq: Calculus II (GIR), 6.100A, and 6.C51
G (Spring)
2-0-4 units

See description under subject 3.C51[J].
R. Gomez-Bombarelli, C. Coley, E. Fraenkel

10.EPE UPOP Engineering Practice Experience
Engineering School-Wide Elective Subject.
Offered under: 1.EPE, 2.EPE, 3.EPE, 6.EPE, 8.EPE, 10.EPE, 15.EPE, 16.EPE, 20.EPE, 22.EPE
Prereq: None
U (Fall, Spring)
0-0-1 units
Can be repeated for credit.

See description under subject 2.EPE. Application required; consult UPOP website for more information.
K. Tan-Tiongco, D. Fordell

10.EPW UPOP Engineering Practice Workshop
Engineering School-Wide Elective Subject.
Offered under: 1.EPW, 2.EPW, 3.EPW, 6.EPW, 10.EPW, 16.EPW, 20.EPW, 22.EPW
Prereq: 2.EPE
U (Fall, IAP, Spring)
1-0-0 units

See description under subject 2.EPW. Enrollment limited to those in the UPOP program.
K. Tan-Tiongco, D. Fordell

10.S28 Special Laboratory Subject in Chemical Engineering
Prereq: Permission of instructor
U (Fall)
Not offered regularly; consult department
2-8-5 units

Laboratory subject that covers content not offered in the regular curriculum. Consult department to learn of offerings for a particular term. Enrollment limited.
J.-F. Hamel

10.S94 Special Problems in Chemical Engineering
Prereq: Permission of instructor
U (IAP)
Units arranged
Can be repeated for credit.

Focuses on problem of current interest not covered in regular curriculum; topic varies from year to year.
Staff

10.S95 Special Problems in Chemical Engineering
Prereq: None
G (Fall, Spring)
Not offered regularly; consult department
Units arranged
Can be repeated for credit.

Focuses on problem of current interest not covered in regular curriculum; topic varies from year to year.
M. Z. Bazant

10.S96 Special Problems in Chemical Engineering
Prereq: None
G (Fall, IAP, Spring)
Units arranged [P/D/F]
Can be repeated for credit.

Focuses on problem of current interest not covered in regular curriculum; topic varies from year to year.
H. D. Sikes

10.TAC Teaching Experience in Chemical Engineering (New)
Prereq: Permission of instructor
G (Fall, IAP, Spring, Summer)
Units arranged [P/D/F]
Can be repeated for credit.

For teaching assistants in chemical engineering, in cases where teaching assignment is approved for academic credit by the department. Development of laboratory, field, recitation, or classroom teaching skills through practical experience in laboratory, field, recitation, or classroom teaching under supervision of a faculty member. Total enrollment limited by availability of suitable teaching opportunities.
H. Sikes

10.THG Graduate Thesis
Prereq: Permission of instructor
G (Fall, IAP, Spring, Summer)
Units arranged
Can be repeated for credit.

Program of research leading to the writing of an SM, PhD, or ScD thesis; to be arranged by the student and appropriate MIT faculty member.
D. Blankschtein

10.THU Undergraduate Thesis
Prereq: None
U (Fall, IAP, Spring, Summer)
Units arranged
Can be repeated for credit.

Program of research leading to writing an SB thesis; topic arranged between student and MIT faculty member.
B. S. Johnston

10.UAR Individual Laboratory Experience
Prereq: 5.310, 7.002, or (*Coreq: 12 units UROP or other approved laboratory subject* and permission of instructor)
U (Spring)
1-0-5 units

Companion subject for students pursuing UROP or other supervised project experience. Instruction in responsible conduct of research and technical communication skills. Concurrent enrollment in an approved UROP or other supervised project required. Limited to Course 10 juniors and seniors; requires advance enrollment application subject to instructor approval.
W. A. Tisdale

10.UR Undergraduate Research
Prereq: None
U (Fall, IAP, Spring, Summer)
Units arranged [P/D/F]
Can be repeated for credit.

Opportunity for participation in the work of a research group, or for special investigation in a particular field. Topic and hours to fit individual requirements.
B. S. Johnston

10.URG Undergraduate Research
Prereq: None
U (Fall, IAP, Spring, Summer)
Units arranged
Can be repeated for credit.

Opportunity for participation in a research group, or for special investigation in a particular field. Topic and hours to fit individual requirements.
B. S. Johnston