Chemical and Biochemical Engineering

Chair

Jun Wang

Undergraduate major: chemical engineering (BSE)

Graduate degrees: MS in chemical and biochemical engineering; PhD in chemical and biochemical engineering

Faculty: https://engineering.uiowa.edu/cbe/people

Website: https://engineering.uiowa.edu/cbe

Chemical and biochemical engineers integrate chemical, physical, biological, and computational elements to solve problems and create products that benefit society. Chemical engineers drive innovation in a wide variety of technologies, including energy and fuels, computer chips, pharmaceuticals, biotechnology, advanced materials, consumer goods, waste treatment, decarbonization, and more. Biochemical engineers work on challenges such as turning crops into sustainable fuels and mass producing vaccines.

The Department of Chemical and Biochemical Engineering has six research areas: air quality and climate, biological and pharmaceutical engineering, machine learning and simulation, polymers and advanced materials, remote and smart sensing, and sustainable energy and clean water. Additionally, the program offers 13 different focus areas for undergraduates to specialize in, providing them with the skills and knowledge to excel in these fields.

The program offers a wide range of opportunities and support to help each student succeed, including personalized mentoring, a strong alumni network, and hands-on learning. Students can enhance their education by participating in co-ops and internships, conducting undergraduate research, pursuing minors and certificates, and choosing a five-year undergraduate to graduate option, earning both a bachelor's and master's degree in just five years.

As part of their training, Iowa chemical and biochemical engineers learn to design things in ways that are ethical and responsible. This includes considering health, employee safety, and global impact. The University of Iowa is a leader in chemical process safety education, teaching effective communication and environmentally conscious design.

Programs

Undergraduate Program of Study

Major

- Major in Chemical Engineering (Bachelor of Science in Engineering)

Graduate Programs of Study

- Master of Science in Chemical and Biochemical Engineering
- Doctor of Philosophy in Chemical and Biochemical Engineering

Facilities

Chemical engineers at the University of Iowa, whether undergraduates or graduate students, benefit from the extensive resources of a top research university. Some of the key facilities and resources available to them include libraries, computing centers, machine and electronics shops, a tool library, prototyping and design studios, chemical analysis and microscopy resources, genetic, cell, and tissue analysis facilities, tutoring and writing centers, and other specialized research infrastructure. These resources are utilized according to each student's customized curriculum and research needs, ensuring they get the most out of their education and training. Specific laboratories maintained by the Department of Chemical and Biochemical Engineering to support undergraduate courses are listed as follows.

Materials Science Laboratory

The Materials Science Laboratory allows students in ENGR:2720 Materials Science to delve deeper into the concepts taught in class. It features tensiometers, hardness testers, an Izod impact tester, a contact angle goniometer, and heat treatment/sintering furnaces to characterize and examine the mechanical properties of a variety of materials. Additionally, students use optical microscopes, metallography specimen kits, and crystallography packages to gain hands-on experience of how material properties are related to their structure.

Chemical Engineering Laboratory

The Chemical Engineering Laboratory provides hands-on learning for undergraduate students in CBE:3150 Thermodynamics/Transport Laboratory and CBE:3155 Chemical Reaction Engineering/Separations Laboratory. The lab is equipped for student experimentation in thermodynamics, fluid flow, heat transfer, mass transfer, chemical reaction engineering, and separations. Much of the lab equipment is made of transparent materials so students can see exactly how things work inside. Additional equipment includes a fluid friction apparatus, a jacketed kettle, and a membrane gas separator. Students use state-of-the-art portable analytical devices in their investigations, including densitometers, polarimeters, and refractometers.

Additionally, a wide array of small equipment is available to support laboratory projects and demonstrations in chemical engineering courses and for use by students performing independent investigations or student groups competing in national chemical engineering contests.

Chemical Process Safety Laboratory

The Chemical Process Safety Laboratory is an integral part of CBE:3125 Chemical Process Safety. Through a series of experiments, students learn about flammability, reactivity, explosions, safety valve design, and electrostatics—all crucial for working safely in the chemical industry. The laboratory is equipped with two MiniFlash automatic flash point testers (closed cup), an advanced reactive system screening tool (ARSST), a minimum ignition energy (MIE) apparatus, a flammability chamber, a modified Hartmann tube, a Hartmann bomb, a liquid conductivity apparatus, a powder chargeability apparatus, a powder volume resistivity apparatus, a Van de Graaff generator, two high impedance electrometers, a field meter, a Faraday cage, and relief sizing software.

Biochemical Engineering Laboratory

The Biochemical Engineering Laboratory is an integral part of CBE:3205 Introduction to Biochemical Engineering. Students use this equipment to perform recombinant DNA experiments and to study the growth and metabolism of microorganisms. The lab is equipped with two controlled New Brunswick BioFlo/CelliGen 115 bioreactors, electrophoresis apparatus, and a thermocycler.

Process Control Laboratory

The Process Control Laboratory is used in CBE:4105 Process Dynamics and Control in Design and CBE:5199 Contemporary Topics: Chemical and Biochemical Engineering. In this lab, students use industrial-grade computer-controlled systems to manage flow, levels, composition, and temperature in pilot-scale devices. Students learn software tools, including DeltaV, a common industrial control system, and LabVIEW, a widely used scientific and engineering measurement and automation system.

Learning modules in the Process Dynamics lab focus on actuators (such as valves and motors), valve positioners, sensors, SCADA (supervisory control and data acquisition) software, distributed control system software, control block diagrams, piping and instrumentation diagrams, mathematical modeling of dynamic systems, and the specification of mathematical transfer functions for chemical, physical, and control operations.

CBE:5199 Contemporary Topics: Chemical and Biochemical Engineering is an introduction to the design and programming of DeltaV-based control systems. Students create a DeltaV operator screen for hardware selected from the process control lab. This allows students to integrate hardware and software and achieve computer control by implementing all project phases: (i) design, (ii) programming, (iii) hardware integration, and (iv) testing and troubleshooting.

Graduate Facilities and Laboratories

The department offers a wide variety of facilities to support and develop research activities.

Air Quality, Climate, Remote Sensing, and Smart Sensing Research Thrusts

The department maintains extensive facilities for computational, field, and laboratory studies of air pollution in the context of climate change. Part of this infrastructure is housed at the Center for Global and Regional Environmental Research (CGRER). The center occupies 5,000 square feet of lab and office space on the fourth floor of the Iowa Advanced Technology Laboratories. CGRER members have dedicated queues and storage within the University of Iowa's extensive High Performance Computing (HPC) facility.

Individual professors maintain a wide variety of air pollution sampling equipment, with a focus on both aerosol and gas-phase physics and chemistry in the context of climate, weather, and human health.

The Atmospheric and Environmental Research (AER) Lab has a diverse research portfolio that encompasses three research themes: development of remote sensing theory and algorithms for characterizing atmospheric (aerosol) particles and surface emissions (especially from fires); development and application of chemistry-aware atmospheric models and observation data to studies in air quality, weather, and climate; and interdisciplinary research via collaborative teamwork in such areas as air quality and public health, irrigation and climate change, environmental monitoring and solutions via community science and engagement.

The Iowa Atmospheric Sensor Development Laboratory (IASDL) is a fully equipped research laboratory dedicated to developing new remote sensing instruments to study the Earth's atmosphere. Focused on laser-based, or lidar, remote sensing, researchers in IASDL develop sensors for use in ground-based, airborne, and spaceborne applications. Advanced technologies and onboard machine learning processing are the basis for creating affordable sensors that produce real-time data products to impact air quality, human health, and decision-making. Researchers in IASDL frequently work with the Operator Performance Laboratory, which is home to several research aircraft, and collaborate with researchers at NASA and other organizations.

Biochemical Engineering

Biochemical engineering laboratories provide facilities for the preparation of biological media and the cultivation of organisms, as well as for the separation and analysis of biomolecules. This equipment includes biological incubators and floor incubator shakers, agitated and airlift bioreactors, light microscopes, autoclaves, Vi-Cell cell counter, thermocycler for polymerase chain reaction (PCR) amplification of DNA, high- and low-speed centrifuges, UV-Vis spectrophotometers, a lyophilizer, biological safety cabinets, and an anaerobic glove box. Phase-contrast and epifluorescence microscopes, gel electrophoresis systems, gas chromatography units with flame ionization and electron capture detectors, and several high-performance liquid chromatography systems with refractive index and photodiode array detectors are available for the characterization of microorganisms and constituent biomolecules.

Through collaborative research agreements, graduate students also have access to specialized facilities for electron microscopy, large-scale fermentation, protein structure, recombinant DNA research, and tissue culture/hybridoma; the Flow Cytometry Facility; and the High Resolution Mass Spectrometry Facility.

Biomedical Engineering

The biomedical engineering laboratories house particle technology equipment including microemulsion equipment for drug encapsulation, sonicators, benchtop scale spray dryers, laser diffraction particle sizer, zetapotentiometer; DNA preparation equipment, gel electrophoresis apparatus; interfacial stress rheometer, surface tensiometer, UV-Vis/fluorescent plate reader, high performance liquid chromatograph, luminometer, lyophilizer, custom-built simulated cough machine, microscopes, incubators, wet chemistry equipment, rotary shakers, incubated plate shakers, autoclave, centrifuges, and laboratory computers. Cell culture and bacterial culture facilities are housed adjacent to the laboratories.

Graduate students also have access to core research facilities, including the Central Microscopy Research Facility, Flow Cytometry Facility, Iowa Institute of Human Genetics, Electron Spin Resonance Facility, Nuclear Magnetic Resonance Facility, High Resolution Mass Spectrometry Facility, and the Center for Gene Therapy.

Computer Facilities

The departmental computer facilities contain a variety of laptops, desktop workstations, and printers. The department is supported by the college's Engineering Technology Center, which maintains a large network of high-performance Linux and Windows workstations along with extensive commercial and public domain software. The department has access to the university's central high-performance research computing facility through ITS–Research Services. The University of Iowa also has access to the ACCESS and Blue Waters national supercomputing resources and is a founding member of the Great Lakes Consortium for Petascale Computing. Locally hosted long-term data storage services are available.

Fundamentals and Applications of Photopolymerization

The Photopolymerization Center was established to advance a fundamental understanding of the kinetics and mechanisms of photopolymerizations. To this end, the center provides unique opportunities for collaborations by industrial and academic investigators to explore photopolymerization processes and develop novel applications based on photopolymerizations.

The center provides equipment and instrumentation for the characterization of photopolymerization systems on the molecular, microscopic, and macroscopic levels. Center researchers pursue an understanding of fundamental photophysical and photochemical processes involved in the photoinitiation reaction, characterization of high-speed propagation and termination kinetics that lead to the polymer structure, and evaluation of material properties through the course of the photopolymerization reaction. Both radical and cationic photopolymerizations are studied with state-of-the-art experimental techniques to elucidate the complex chemical and physical mechanisms that control the initiation, propagation, and termination of the active centers.

Machine Learning and Artificial Intelligence Resources

In addition to specialized software developed and maintained by researchers in the Chemical and Biochemical Engineering department, students, staff, and faculty also make use of the university's High Performance Computing (HPC) resources and the Iowa Institute for Artificial Intelligence (IIAI). HPC resources include GPU processors that are particularly useful for running machine learning algorithms. The Iowa Institute for Artificial Intelligence helps department researchers transform ideas for machine learning and artificial intelligence applications from concepts to working code.

Electrochemical Engineering

The electrochemical engineering laboratories house facilities for electrocatalyst synthesis and characterization, located in the Iowa Advanced Technology Laboratories (IATL). The equipment includes muffle furnaces and tube furnaces for materials synthesis, optical microscopes for surface characterization, rotating disk electrode (RDE) and rotating ring-disk electrode (RRDE) systems with rotators for electrochemical measurements, flow cells and electrolyzers for device testing, potentiostats/galvanostats (electrochemical workstations), and scanning electrochemical microscope (SECM) for local electrochemical analysis. Three-dimensional printers are available for fabricating customized equipment components and accessories for fluid handling and control. Graduate students also have access to core research facilities, including the Central Microscopy Research Facility, and MATFab Facility.

Courses

Chemical and Biochemical Engineering Courses

CBE:0000 Chemical Engineering Internship/Co-op 0 s.h.
Chemical engineering students participating in the Cooperative Education Program register for this course during work assignment periods; registration provides a record of participation in the program on the student's permanent record. Requirements: admission to Cooperative Education Program.

CBE:1000 CBE Departmental Seminar 1 s.h.
Introduction to the profession and the department; presentations by guest speakers, visits to laboratories and industries.

CBE:1180 First-Year Seminar 1 s.h.
Small discussion class taught by a faculty member; topics chosen by instructor; may include outside activities (e.g., films, lectures, performances, readings, visits to research facilities, field trips). Requirements: first- or second-semester standing.

CBE:2030 Energy and Society 3 s.h.
History of energy development and use throughout the world; how energy has affected the development of human societies; societal impact of engineering advances; current state of energy consumption worldwide, including distribution of energy sources, global variations in consumption, advantages and disadvantages of current energy sources; role of fossil fuel consumption in global climate change, potential scenarios for the future of energy.

CBE:2040 Environment, Energy, and Climate Change 3 s.h.
Traditional concerns (e.g., pollution and conservation of energy resources) with clear, scientific explanations; Earth's dynamic processes and response to natural and human-induced stresses; link between energy and climate; reasons why we need to support reducing emissions and build a clean and sustainable environment.

CBE:2050 Severe and Unusual Weather 3 s.h.
Basic weather concepts behind severe weather phenomena and essential safety information; how weather events cause billions of dollars in damage and thousands of casualties; winter storms can impact half of the nation, paralyzing the transportation network with icy roads and wind driven snow; tornadoes can strike within minutes tearing apart homes; hurricanes can destroy entire communities with strong winds, heavy rain, and deadly storm surge; how understanding severe weather and knowing what to do before, during, and after an event can significantly reduce injury, deaths, and property damage. Same as CEE:2050.

CBE:2105 Material and Energy Balances 3 s.h.
Fundamental principles of chemical process analysis, including material and energy balances for single-unit and multiple-unit processes, analysis of reactive and nonreactive systems, introduction to equations of state, thermodynamics of multiphase systems. Prerequisites: MATH:1550.

CBE:2110 Computational Tools for Chemical Engineers 2 s.h.
Numerical methods for solving systems of linear and nonlinear equations, nonlinear regression, multivariable calculus, and ordinary differential equations using chemical engineering examples. Prerequisites: MATH:1550. Corequisites: MATH:1560.

CBE:3000 Professional Seminar: Chemical Engineering 1 s.h.
Professional aspects of chemical engineering presented through lectures and discussions by guest speakers, plant trips, and panel discussions. Prerequisites: CBE:2105. Requirements: sophomore standing.

CBE:3020 Applied Statistics for Chemical and Natural Resources Engineering 3 s.h.
Statistical and computational (Python programming) analysis of weather and climate data, univariate and multivariate statistics, hypothesis testing, statistical forecasting, forecast verification, time-series analysis, trend analysis, and principal component analysis.

CBE:3105 Chemical Engineering Thermodynamics 3 s.h.
Applications of thermodynamic principles to chemical and physical processes; prediction of material properties; phase and chemical equilibria applied to mixtures and reacting systems. Prerequisites: ENGR:2130. Corequisites: CBE:2105.

CBE:3109 Fluid Flow 2 s.h.
Fundamentals of fluid flow, including fluid statics, fluid rheology, laminar and turbulent flow in pipes, external flow, flow through packed beds, fluidized beds, pumps and compressors, boundary layer theory, potential flow, dimensional analysis, and Navier Stokes Equations. Corequisites: CBE:2105.

CBE:3113 Heat and Mass Transfer 3 s.h.
Fundamentals of heat and mass transfer including heat exchanger design; conductive, convective, and radiative heat transfer; mechanisms of diffusional and convective mass transfer. Prerequisites: MATH:2560 and CBE:2105. Recommendations: CBE:3109.

CBE:3117 Separations 3 s.h.
Solution of industrial problems including design of distillation, extraction, absorption, adsorption, drying, membrane processes, and mechanical separations. Prerequisites: CBE:2105 and CBE:3105. Corequisites: CBE:3113.

CBE:3120 Chemical Reaction Engineering 3 s.h.
Application of chemical reaction kinetics to design of chemical reactors: batch reactors, mixed flow reactors, plug flow reactors; reversible and irreversible single reactions; parallel, series, and mixed reactions; temperature and pressure effects on reactor design; heterogeneous catalysis; transport in porous catalysts. Prerequisites: MATH:2560. Corequisites: CBE:3105. Recommendations: CBE:3113.

CBE:3125 Chemical Process Safety 3 s.h.
Application of transport phenomena, thermodynamics, chemical kinetics to study of safety, health, loss prevention; government regulations, toxicology/industrial hygiene, relief sizing, runaway reactions, toxic release and dispersion models, source models, fires and explosions, risk assessment, hazard identification, case studies and accident investigation, incorporation of safety into design; laboratory experiments. Prerequisites: CBE:3105 and CBE:3109. Corequisites: CBE:3113.

CBE:3150 Thermodynamics/Transport Laboratory 3 s.h.
Error analysis, propagation of errors, experimental design, data collection techniques, report writing, oral presentations, laboratory safety; laboratory investigations of thermodynamics, fluid flow, heat transfer, fluid rheology. Prerequisites: CBE:3105 and CBE:3113. Recommendations: STAT:2020 or CBE:3020.

CBE:3155 Chemical Reaction Engineering/Separations Laboratory 3 s.h.
Experimental design, data collection techniques, report writing, oral presentations; laboratory investigations of chemical reaction engineering and separations; experiments with plug flow and batch reactors, distillation, evaporation, membrane separation. Prerequisites: CBE:3117. Corequisites: CBE:3120. Recommendations: STAT:2020.

CBE:3205 Introduction to Biochemical Engineering 3 s.h.
Biochemistry, cellular biology, recombinant DNA and hybridoma technologies; emphasis on engineering aspects of biotechnology, including enzyme kinetics, cell growth kinetics, transport phenomena in bioreactors, bioreactor design, bioseparations, formulation and sterilization of growth media, commercial applications of biotechnology. Prerequisites: CBE:2105. Corequisites: CBE:3109. Recommendations: CBE:3120.

CBE:3405 Green Chemical and Energy Technologies 3 s.h.
Strategies for pollution prevention for chemical processes studied at macroscale (industrial sector), mesoscale (unit operations), and microscale (molecular level); case studies. Prerequisites: CHEM:1070 or CHEM:1110.

CBE:3415 Statistical and Computational Analysis of Weather and Climate Data 3 s.h.
Statistical and computational (Python programming) analysis of weather and climate data, univariate and multivariate statistics, hypothesis testing, statistical forecasting, forecast verification, time-series analysis, principal component analysis, trend analysis, and cluster analysis. Requirements: senior or graduate standing.

CBE:3998 Individual Investigations: Chemical Engineering arr.
Individual projects for chemical engineering undergraduate students, such as laboratory study, engineering design project, analysis and simulation of an engineering system, computer software development, research.

CBE:4105 Process Dynamics and Control in Design 3 s.h.
Theory and application of process dynamics to the design of chemical process control systems; mathematical models of unit operations, transfer functions, feedback and feed-forward control, stability, instrumentation, digital control systems; computer methods, including simulation and commercial software use; laboratory focus on process analysis and design. Prerequisites: MATH:2560 and CBE:2105 and CBE:3109. Corequisites: CBE:3120.

CBE:4109 Chemical Engineering Process Design I 2 s.h.
Engineering economics of process evaluation, including time value of money and bases for cost estimation; preliminary design of chemical process plants using computer-aided engineering. Prerequisites: CBE:3109 and CBE:3113 and CBE:3117. Corequisites: CBE:3120 and CBE:3125.

CBE:4110 Chemical Engineering Process Design II 3 s.h.
Capstone chemical engineering course; design and optimization of chemical process plants; application of process calculations, thermodynamics, kinetics, process synthesis, energy efficiency in separations, heat-exchanger network synthesis, physical property estimation, safety, computer-aided design, unit operations theory, process control, and economics. Prerequisites: CBE:4109. Recommendations: CBE:4105 and CBE:3205.

CBE:4125 Advanced Chemical Process Safety 3 s.h.
Chemical process safety including qualitative and quantitative hazard analysis, risk and consequence analysis, human factors and operator error, incident investigation, management of change procedures, interlocks and safety instrumented systems, layer of protection analysis, dust hazard analysis, and process safety management. Prerequisites: CBE:3125.

CBE:4195 Senior Enriching Activities Seminar 0 s.h.
Aspects of chemical engineering education, including multidisciplinary team skills, understanding the impact of engineering practice locally and globally. Corequisites: CBE:4110. Requirements: completion of enriching activity.

CBE:4410 Sustainable Systems 3 s.h.
New and emerging concepts in sustainable systems design and assessment. Same as CEE:4107.

CBE:4420 Environmental Chemistry 3 s.h.
Principles of general, physical, organic chemistry applied in water and air systems; emphasis on qualitative and quantitative understanding of chemical kinetics and equilibrium; acid-base reactions, complex formation, precipitation, dissolution, and oxidation-reduction reactions; organic nomenclature. Prerequisites: CHEM:1120. Same as CEE:4150.

CBE:4459 Air Pollution Control Technology 3 s.h.
Sources, environmental and health impacts, regulations, modeling of air pollution; processes and alternative strategies for control; global climate considerations. Same as CEE:4159, IGPI:4159.

CBE:4460 Process and Design for Satellites and Environmental Sensors 3 s.h.
Exploration of how to design, develop, and implement science instruments, sensor networks, and satellite mission; emphasis on atmospheric sensors for planetary atmospheres; disciplines required, how to build a team, developing science requirements, developing instrument requirements, development and management of interface controls, workflow tracking, quality assurance verification, and resolving hardware/design problems; considerations needed by a principal investigator, instrument manager, instrument scientist, plan manager, or systems engineer to pursue a major instrument, mission development, industrial plan development, or expansion.

CBE:5000 Seminar in Chemical and Biochemical Engineering 1 s.h.
Presentation and discussion of recent advances and research in chemical and biochemical engineering by guest lecturers, faculty, students. Requirements: graduate standing.

CBE:5100 Graduate Professional Development Seminar 1 s.h.
Seminar participants work with a faculty member to select and attend eight hours of approved seminars and professional development trainings at the University of Iowa; final meeting of participants is held to share notable seminars; typical seminar series include College of Engineering lectures, departmental and research center graduate seminars, chemical and biochemical engineering professional seminar series, and Center for Teaching and Learning offerings. Requirements: master's standing in chemical and biochemical engineering.

CBE:5104 Introduction to Literature Review and Technical Writing 3 s.h.
Review of technical literature, how to contribute to it; produce and present orally a peer-reviewed-journal-quality review article; brainstorming, group writing, research ethics, plagiarism. Recommendations: nonthesis track graduate standing.

CBE:5105 Introduction to Literature Review and Proposal Writing 3 s.h.
Tools for reviewing literature, skills for critical reading of publications, training in successful proposal writing; experience drafting a proposal that can be used as a starting point for the PhD comprehensive.

CBE:5110 Intermediate Thermodynamics 3 s.h.
Fundamental principles of thermodynamics as applied to phase equilibrium; properties of fluids, first and second law, variable composition systems, behavior of real fluids, mathematical techniques for solution thermodynamics. Requirements: CBE:3105 or ME:4160 or graduate standing. Same as ME:5210.

CBE:5115 Transport Phenomena I 3 s.h.
Unified treatment of momentum, mass, energy transport in chemical engineering problems; use of vector and tensor notations in expressing equations of continuity, motion, energy.

CBE:5120 Data Science in Chemical and Engineering Systems 3 s.h.
Theory and application of numerical methods and data driven algorithms towards understanding chemical processes; scientific computing in Python programming language; numerical solutions to differential equations; nonlinear and constrained optimization; data preprocessing and visualization; dimensionality reduction and clustering; supervised machine learning.

CBE:5140 Mathematical Methods in Engineering 3 s.h.
Linear ordinary differential equations, series solutions of differential equations, special functions, Laplace transforms, Fourier series, matrices, linear systems, eigenvalue problems, second-order partial differential equations. Prerequisites: MATH:2550 and MATH:2560. Same as CEE:5513, ME:5113.

CBE:5199 Contemporary Topics: Chemical and Biochemical Engineering arr.
Research techniques for graduate students in chemical and biochemical engineering.

CBE:5210 Bioseparations 3 s.h.
Unit operations used to isolate and purify biologically derived chemicals, including flocculation, filtration, centrifugation, extraction, adsorption, chromatography, precipitation, crystallization, electrophoresis and cell disruption for intracellular product recovery.

CBE:5310 Polymer Science and Technology 3 s.h.
Uses and properties of industrially important polymeric materials; polymer chemistry, polymer structure, characterization, and polymer processing. Prerequisites: CHEM:2210 or CHEM:2230.

CBE:5315 Polymer Chemistry 3 s.h.
Monomer reactivity and polymerization reactions; step, radical, ionic, and ring-opening polymerizations. Prerequisites: CHEM:2220.

CBE:5390 Photopolymerization Topics 1 s.h.
Seminars presented by faculty members, research assistants, students.

CBE:5410 Electrochemical Engineering 3 s.h.
Fundamentals of electrochemical engineering; various applications; focus on processes and systems that transform chemical energy into electrical energy (e.g., batteries, fuel cells) and vice versa (e.g., electrolyzers, oxygen generators for medical applications); electrochemical engineering in an increasingly important role in energy, chemical, environmental, and biomedical sectors.

CBE:5412 Atmospheric Modeling 3 s.h.
Model equations and approaches for atmospheric dynamics and chemistry; numerical methods for radiative, chemical, and aerosol rates; parameterization of subgrid-scale processes; model evaluation and inverse modeling.

CBE:5415 Satellite Image Processing and Remote Sensing of Atmosphere 3 s.h.
Introduction to principles of atmospheric radiation and techniques for satellite image processing; hands-on experience with data calibration, image registration and enhancement, noise filtering and (supervised and unsupervised) multi-spectral classification of satellite imageries; various satellite sensors used for monitoring of different atmospheric processes and constituents. Same as IGPI:5415.

CBE:5417 Physical Meteorology and Atmospheric Radiative Transfer 3 s.h.
Physical processes for weather and climate including radiative transfer, cloud and precipitation formation, and atmospheric electricity; theory of scattering by atmospheric particles (e.g., clouds, aerosols, molecules), atmospheric radiative transfer equations, and numerical techniques and tools to solve these equations. Requirements: senior or graduate standing. Same as CEE:5417, IGPI:5417.

CBE:5425 Atmospheric Chemistry and Physics 3 s.h.
Principal chemical and physical processes affecting atmospheric trace gas and pollutant cycles; emphasis on atmospheric photochemistry, aerosol science, major sources, and removal processes. Corequisites: CBE:3120. Same as CEE:5115.

CBE:5466 Optical Components, Alignment, and Instrumentation for Remote Sensing 3 s.h.
Explore optical components including lenses, mirrors, beam splitters, fiber optics, and filters, and optical assemblies including beam expanders, interferometers, and laser cavities; assess and align optical assemblies using metrology equipment including collimators, autocollimators, and wavemeters; hands-on laboratory work. Work with optics, optical devices, and metrology equipment; learn how to handle, work with, and assess optics and optical components and how to align complex assemblages of components in a sensor. Recommendations: basic or introductory physics course with applications to atmospheric chemistry. Same as ECE:5466, PHYS:5466.

CBE:5740 Engineering Principles of Drug Delivery 3 s.h.
Fundamental concepts in drug delivery from an engineering perspective: delivery mechanisms; materials and formulations for drug delivery; drug modifications (prodrugs, PEGylation); engineering principles of controlled release and targeted delivery (nanoparticles, microparticles, polymer and lipid based systems); quantitative understanding of drug transport; significance of biodistributions and pharmacokinetic models; toxicity issues; immune responses.

CBE:5875 Perspectives in Biotechnology 1 s.h.
Topics related to careers in biotechnology with an emphasis on preparing graduate students for careers outside of academia; discussions led by a series of guest speakers from leading biotech industries; understanding the societal impact of basic research; participation in round-table discussions; and presentation of student research findings. Requirements: graduate standing and good academic standing in a participating department supported by the Predoctoral Training Program in Biotechnology. Same as BMB:5875, CEE:5875, CHEM:5875, MICR:5875, PHAR:5875.

CBE:5998 Individual Investigations: Chemical and Biochemical Engineering arr.
Individual projects for chemical and biochemical engineering graduate students; may include laboratory study, engineering design project, analysis and simulation of an engineering system, computer software development, research. Requirements: graduate standing.

CBE:5999 MS Thesis Research: Chemical and Biochemical Engineering arr.
Experimental and/or analytical investigation of an approved topic for partial fulfillment of requirements for MS with thesis in chemical and biochemical engineering. Requirements: graduate standing.

CBE:6145 Diffusive Transport 3 s.h.
Diffusive transport of heat, mass, and momentum; phenomenological laws and analogies; analytical and numerical solution techniques; inverse heat conduction; multiphase and multicomponent systems. Prerequisites: ME:5145. Same as ME:6245.

CBE:6415 Advanced Satellite and Remote Sensing of Atmosphere 3 s.h.
Cloud masking and retrieval of cloud properties from satellites, aerosol detection and retrievals, Earth radiation energy budget, land and/or ocean remote sensing, microwave remote sensing, wind retrieval, multi-sensor intercomparison and validation, optimization and inversion theory; hands-on projects.

CBE:6435 Advanced Atmospheric Radiative Transfer 3 s.h.
Theory of scattering by atmospheric particles (e.g., clouds, aerosols, molecules), atmospheric radiative transfer equations, and techniques to solve these equations for solar and terrestrial radiation; numerical experiments with Mie scattering, T-matrix calculation, and radiative transfer models.

CBE:7999 Research: Chemical and Biochemical Engineering PhD Dissertation arr.
Experimental and/or analytical investigation of an approved topic for PhD in chemical and biochemical engineering.