CHBE - CHEMICAL AND BIOMOLECULAR ENGINEERING

CHBE409 Undergraduate Honors Seminar (1 Credit)
Students will attend and write summaries of departmental seminars, along with professional development activities
Restriction: Must be in a major within the ENGR-Chemical & Biomolecular Engineering department; and Permission of ENGR-Chemical & Biomolecular Engineering department; and Must be in the Chemical Engineering Honors Program.
Repeatable to: 2 credits.

CHBE410 Statistics and Design of Experiments (3 Credits)
An introduction to probability, statistics, and design of experiments for chemical engineers.
Prerequisite: Minimum grade of C- in CHBE250, MATH241, and MATH246.
Restriction: Must be in a major within the ENGR-Chemical & Biomolecular Engineering department; and permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE410 or ENCH476.
Formerly: ENCH476.

CHBE422 Chemical and Biomolecular Engineering Transport Phenomena I (3 Credits)
Principals of fluid dynamics as applied to model development and process design. Mass, momentum and energy conservation. Statics and surface tension. Equation of Continuity and Navier-Stokes Equation with application to laminar flow. Dimensional analysis. Macroscopic balances, Bernoulli Equation and friction factors with application to turbulent flow.
Prerequisite: Minimum grade of C- in CHBE101, CHBE250, MATH241, and MATH246.
Restriction: Must be in a major within the ENGR-Chemical & Biomolecular Engineering department; and permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE422 or ENCH422.
Formerly: ENCH422.

CHBE424 Chemical and Biomolecular Engineering Transport Phenomena II (3 Credits)
Principles of mass and heat transfer as applied to model development and process design. Species continuity equation with application to diffusion, and convection in laminar flow. Macroscopic balances and mass transfer coefficients with application to turbulent flow. Microscopic equation of energy with application to heat conduction, and convection in laminar flow. Macroscopic energy balance and heat transfer coefficients with application to turbulent flow. Heat exchanger design.
Prerequisite: CHBE422.
Corequisite: CHBE302.
Restriction: Must be in Engineering: Chemical program; and permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE424 or ENCH424.
Formerly: ENCH424.

CHBE426 Chemical and Biomolecular Separation Processes (3 Credits)
Separation by stages operations. Rate dependent separation processes. Design application in distillation, gas absorption, liquid extraction, drying, adsorption and ion exhange.
Corequisite: CHBE302; and CHBE424.
Restriction: Must be in Engineering: Chemical program; and permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE426 or ENCH426.
Formerly: ENCH426.

CHBE437 Chemical and Biomolecular Engineering Laboratory (3 Credits)
Application of chemical engineering process and unit operation principals in small-scale semi-commercial equipment. Data from experimental observations are used to evaluate performance and efficiency of operations. Emphasis on correct presentation of results inreport form.
Prerequisite: CHBE424, CHBE426, and CHBE440.
Restriction: Must be in a major within ENGR-Chemical & Biomolecular Engineering department; and permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE437 or ENCH437.
Formerly: ENCH437.

CHBE440 Chemical Kinetics and Reactor Design (3 Credits)
Fundamentals of chemical reaction kinetics and their application to the design and operation of chemical reactors. Reaction rate theory, homogeneous reactions and catalysis electrochemical reactions. Catalytic reactor design.
Prerequisite: Minimum grade of C- in CHBE301, MATH241, and MATH246.
Restriction: Must be in Engineering: Chemical program; and permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE440 or ENCH440.
Formerly: ENCH440.

CHBE442 Chemical and Biomolecular Systems Analysis (3 Credits)
Dynamic response applied to process systems. Goals and modes of control, Laplace transformations, analysis and synthesis of simple control systems, closed loop response, dynamic testing.
Prerequisite: CHBE424 and CHBE426.
Credit Only Granted for: CHBE442 or ENCH442.
Formerly: ENCH442.

CHBE444 Process Engineering Economics and Design I (3 Credits)
Principles of chemical engineering economics and process design. Equipment sizing and costing. Economic evaluation of projects. Flowsheet synthesis. Introduction to flowsheet simulators and concepts of flowsheet optimization. Synthesis of Heat Exchanger Networks and Distillation Sequences.
Prerequisite: CHBE424, CHBE426, and CHBE440.
Restriction: Must be in a major within the ENGR-Chemical & Biomolecular Engineering department; and permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE444 or ENCH444.
Formerly: ENCH444.

CHBE446 Process Engineering Economics and Design II (3 Credits)
Application of chemical engineering principles for the design of chemical processing equipment. Representative problems in the design of chemical plants will be the focus of this capstone design class. Comprehensive reports are required.
Prerequisite: CHBE442 and CHBE444.
Restriction: Must be in a major within the ENGR-Chemical & Biomolecular Engineering department; and permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE446 or ENCH446.
Formerly: ENCH446.

CHBE451 Photovoltaics: Solar Energy (3 Credits)
The emphasis of the class is on developing a conceptual understanding of the device physics and manufacturing processes of crystalline and thin-film photovoltaic cells, and to develop elementary computational skills necessary to quantify solar cell efficiency. The class material includes detailed, system-level energy balances necessary to understand how solar energy fits into the complete energy generation, conversion, and storage picture. Quantitative comparisons of PV technology to solar chemical conversion processes and biofuels are made.
Jointly offered with: CHBE651.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: ENCH468L, CHBE451 or CHBE651.
Formerly: ENCH468L.

CHBE452 Introduction of Machine Learning in Chemical Engineering (3 Credits)
Introduction of data science and machine learning approaches to modern problems in chemical engineering and materials science. This course develops data science approaches, including their foundational mathematical and statistical basis, and applies these methods to data sets of limited size and precision. Methods for regression and clustering will be developed and applied, with an emphasis on validation and error quantification. Techniques that will be developed include linear and nonlinear regression, clustering and logistic regression, dimensionality reduction, unsupervised learning, and artificial neural networks. These methods will be applied to a range of engineering problems, including conducting polymers, stretchable conductors, organic synthesis, and quality control in manufacturing.
Recommended: Basic knowledge of chemical engineering, materials science, ordinary differential equations, and Python is desirable.
Jointly offered with: CHBE652.
Restriction: Permission of Department or Instructor.
Credit Only Granted for: CHBE452 or CHBE652.

CHBE453 Applied Mathematics and Distributive Parameter Systems (3 Credits)
Mathematical techniques applied to the analysis and solution of chemical engineering problems. Use of differentiation, integration, differential equations, partial differential equations and integral transforms. Application of infinite series, numerical and statistical methods.
Credit Only Granted for: CHBE453 or ENCH453.
Formerly: ENCH453.

CHBE454 Chemical Process Analysis and Optimization (3 Credits)
Application of mathematical models to the analysis and optimization of chemical processes. Models based on transport, chemical kinetics and other chemical engineering principles will be employed.
Credit Only Granted for: CHBE454 or ENCH454.
Formerly: ENCH454.

CHBE455 Model Predictive Control (3 Credits)
Empirical model identification from process data. Step and impulse response models. Linearization of nonlinear first principles models. Single variable Model Predictive Control. Robustness with respect to modeling error. MPC based tuning of PID controllers. Feedforward control. Multi-input multi-output processes. Multi-loop decentralized control. Centralized multivariable Model Predictive Control via on-line optimization.
Credit Only Granted for: CHBE455 or ENCH455.
Formerly: ENCH455.

CHBE457 Design and Processing of Polymers for Biomedical Devices (3 Credits)
Provides a foundation for understanding the use of various materials in medical applications. We will discuss design principles, based on biological context for drug delivery, diagnosis of disease, imaging applications, tissue engineering, among other relevant topics. The course will cover nanomedicine approaches (lipids, polymers, gold nanoparticles, carbon nanotubes, etc.), as well as scaffolds for tissue engineering and regenerative medicine. We will discuss advantages, challenges, and recent advances in the field. The course will highlight the importance of rational engineering when designing products to be used to treat and diagnose disease.
Prerequisite: MATH246; and CHEM231; and (CHBE301, ENMA461, or BIOE232).
Recommended: Knowledge of basic fluid dynamics: CHBE422/BIOE331 or equivalent.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: BIOE453, CHBE457, or ENMA425.

CHBE468 Research (1-3 Credits)
Investigation of a research project under the direction of a faculty member. Comprehensive reports are required.
Restriction: Permission of Chemical and Biomolecular Engineering Department; and must be third or fourth year student; and must have minimum GPA of 3.0; and must have successfully completed all lower level engineering, science and mathematics courses for the major.
Repeatable to: 6 credits.
Formerly: ENCH468.

CHBE469 Special Projects (1-3 Credits)
Special project under the direction of a faculty member. Comprehensive reports are required.
Restriction: Permission of Chemical and Biomolecular Engineering Department; and must be third or fourth year student; and must have minimum GPA of 3.0; and must have successfully completed all lower level engineering, science and mathematics courses for the major.
Repeatable to: 6 credits if content differs.

CHBE470 Colloid and Interface Science (3 Credits)
Introduction to colloidal systems and interfacial science. Topics include preparation, stability and coagulation kinetics of colloidal suspensions. Introduction to DLVO theory, electrokinetic phenomena, colloidal aggregation, interfacial phenomena, double layer theory, surface chemistry. Discussion of interfacial thermodynamics and interfacial forces for solid-liquid interfaces. Applications to nanomaterial synthesis, nanomaterial and polymer self-assembly, protein-protein interactions, and protein aggregation will be discussed.
Prerequisite: CHBE424 and CHBE426.
Jointly offered with: CHBE670.
Restriction: Must be in a major within the ENGR-Chemical & Biomolecular Engineering department; and permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: ENCH648F, CHBE470 or CHBE670.

CHBE471 Particle Science and Technology (3 Credits)
Particles are everywhere. We breathe them, eat them, and use them to make many non-particulate materials. Knowledge of particle science and technology is important for manufacturing, for occupational health and safety, as well as environmental considerations. In this multidisciplinary course, the focus will be on the study of science and technology relevant to multiphase systems consisting of solid and/or liquid particles surrounded by a gas. These topics fall loosely under the headings of powder and aerosol technology. Team design projects will be an integral component.
Prerequisite: Knowledge of undergraduate engineering thermodynamics, and transport phenomena; knowledge of numerical methods for solving systems of ordinary differential equations.
Restriction: Must be in a major within ENGR-Chemical & Biomolecular Engineering department; or permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE471 or ENCH471.
Formerly: ENCH471.

CHBE472 Control of Air Pollution Sources (3 Credits)
Sources and effects of air pollutants, regulatory trends, atmospheric dispersion models, fundamentals of two-phase flow as applied to air pollution and air pollution control systems, design of systems for control of gases and particulate matter.
Jointly offered with: CHBE672.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE472, CHBE672 or ENCH672.

CHBE474 Biopharmaceutical Process Development and Manufacturing (3 Credits)
Covers the fundamental steps involved in process development and manufacturing of biopharmaceuticals. An overview of different classes of biopharmaceuticals as well as manufacturing requirements for clinical development and regulatory approval will be provided. In depth coverage of manufacturing steps including cell culture, purification and formulation as well as drug product manufacturing, analysis and stability will be covered. Scientific literature will be used to highlight current challenges and novel solutions in each step of the manufacturing process. Scale up considerations, GMP requirements and process economics will also be introduced.
Prerequisite: BIOE120; and permission of instructor.
Jointly offered with: CHBE674.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE474, BIOE489T, ENCH648D or CHBE674.

CHBE475 Ethics in Science and Engineering (3 Credits)
Ethical issues in science and engineering and their resolutions are examined. The main topics will be ethics and scientific truth (including issues of proper data analysis, proper data presentation, and record-keeping), ethics and other scientists and engineers (including issues of attribution, confidentiality, conflicts of interest, mentoring, and inclusion of under-represented groups), ethics and the practice of engineering (including responsibilities of engineers to clients, ecological issues, and conflicts of interest), and ethics and society (including funding priorities, moral issues, and human and animal subjects). Class meetings will be organized around discussions, case studies, and student reports. The course is aimed at postdoctoral students, graduate students and advanced undergraduate students who wish to ponder the important contemporary questions about the ethics of how science and engineering get done.
Credit Only Granted for: CHBE475 or ENCH475.
Formerly: ENCH475.

CHBE476 Molecular Modeling Methods (3 Credits)
Statistical mechanics will be introduced to give the fundamental background for atomic to mesoscale molecular modeling. Classical atomic-level simulations methods (Monte Carlo and Molecular Dynamics) and the procedures to develop intra- and intermolecular potentials will be covered. This course will also discuss the theory and application of coarse-grained molecular simulations, mesoscale simulations and other modern simulation techniques. A broad range of applications will be included throughout the semester, e.g., phase behavior of small molecules, kinetics, and biophysics.
Jointly offered with: CHBE476.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: ENCH648P, CHBE476 or CHBE676.
Formerly: ENCH468P.

CHBE477 Mesoscopic and Nanoscale Thermodynamics (3 Credits)
Interdisciplinary course primarily for graduate and senior undergraduate students from engineering or science departments. New emerging technologies deal with bio-membrane and gene engineering, microreactor chemistry and microcapsule drug delivery, micro-fluids and porous media, nanoparticles and nanostructures, supercritical fluid extraction and artifical organs. Engineers often design processes where classical thermodynamics may be insufficient, e.g., strongly fluctuating and nanoscale systems, or dissipative systems under conditions far away from equilibrium.
Prerequisite: A prior course in classical thermodynamics.
Jointly offered with: CHBE477.
Restriction: Must be in a major within the ENGR-Chemical & Biomolecular Engineering department; and permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE477, ENCH468Q or CHBE677.
Formerly: ENCH468Q.

CHBE480 Bionanotechnology: Physical Principles (3 Credits)
Physics at nano/micro scales. Biomolecular building blocks. Simplest biomolecular assembly: protein folding. Nanoscale intermolecular interactions important for biology. Protein-ligand binding. Protein higher-order assembly: filaments, networks. Protein filaments and motility. DNA, RNA and their assembly assisted by proteins. Viral capsid assembly. Lipid assembly into micelles, bilayers. Lipid-protein co-assembly in membranes. Lipid and polymer structures useful in medicine. Targeted delivery of drugs, genes by nano/micro structures. Cellular assembly in the eye, in insect wings. Cellular assembly at surfaces: gecko feet, duck feathers. Cellular assembly in the presence of crystals: biomineralization.
Prerequisite: BIOE120; or students who have taken courses with comparable content may contact the department.
Jointly offered with: CHBE680.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: ENCH648N, CHBE480 or CHBE680.

CHBE481 Transport Phenomena in Small and Biological Systems (3 Credits)
Interdisciplinary course primarily for senior undergraduate and graduate students from engineering or science departments. The course's main goal is to make the students familiar with the fundamental physics and modeling of transport phenomena in small and biological systems, and their current scientific and engineering utilization in microfluidics, nanofluidics and biological systems.
Jointly offered with: CHBE681.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: ENCH468W, CHBE481 or CHBE681.
Formerly: ENCH468W.
Additional Information: Adding graduate course to jointly offered and credit only granted for fields.

CHBE483 Bioseparations (3 Credits)
Engineering fundamentals of separations and purification of biological molecules. Case studies and examples illustrate principles and practice of centrifugation, precipitation, crystallization, filtration, membrane separations, chromatography, and affinity separation of recombinant proteins and other biomolecules. Process scale-up and economics of biotechnology products and processes.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: ENCH483 or CHBE483.
Formerly: ENCH483.

CHBE484 Metabolic Pathway Engineering (3 Credits)
The state-of-the-art in metabolic engineering, with a focus on the analysis and engineering of metabolic pathways through (chemical) engineering principles, will be covered. Topics covered include: (1) overview of biochemistry and metabolism; (2) metabolic flux analysis and isotope labeling illustrated with examples from the recent scientific literature; (3) technologies for engineering metabolic pathways; (4) metabolic control analysis and pathway regulation; (5) applications of metabolic engineering to synthesis of biofuels and therapeutics; (6) specialized and related subjects such as protein engineering and synthetic biology.
Prerequisite: CHBE101 and CHBE440.
Jointly offered with: CHBE684.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: ENCH468M, CHBE484 or CHBE684.
Formerly: ENCH468M.

CHBE485 Biochemical Engineering Laboratory (3 Credits)
Techniques of measuring pertinent parameters in fermentation reactors, quantification of production variables for primary and secondary metabolites such as enzymes and antibiotics, the insolubilization of enzymes for reactors, and the demonstration of separation techniques such as ultrafiltration and affinity chromatography.
Credit Only Granted for: CHBE485 or ENCH485.
Formerly: ENCH485.

CHBE486 Heterogeneous Catalysis for Energy Applications (3 Credits)
Introduction to heterogeneous catalytic science and technology for energy conversion and hydocarbon processing. Preparation and mechanistic characterization of catalyst systems, kinetics of catalyzed reactions, adsorption and diffusion influences in heterogenious reactions. An overview of heterogeneous catalysis in various energy-related applications, including petroleum refining, chemicals from biomass, valorization of shale gas, and CO2 utilization will be introduced.
Prerequisite: Minimum grade of C- in CHBE302, CHBE424, and CHBE440; and permission of instructor.
Restriction: Must be in a major within the ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE486, CHBE686 or ENCH686.

CHBE487 Tissue Engineering (3 Credits)
A review of the fundamental principles involved in the design of engineered tissues and organs. Both biological and engineering fundamentals will be considered.
Prerequisite: Must have completed at least one biology course; and MATH241.
Recommended: BSCI330 and BIOE340.
Restriction: Must be in a major within the ENGR-Chemical & Biomolecular Engineering department; or permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: BIOE411, CHBE487, or ENCH468T.
Formerly: ENCH468T.

CHBE490 Polymer Science (3 Credits)
The elements of the polymer chemistry and industrial polymerization, polymer structures and physics, thermodynamics of polymer solutions, polymer processing methods, and engineering applications of polymers.
Credit Only Granted for: CHBE490, ENCH490, or ENMA495.
Formerly: ENCH490.

CHBE493 Chemical Processes in Beer Brewing (3 Credits)
Covers chemical engineering principles and chemical processes involved in the brewing and quality control of beer. Topics will include extraction and isomerization of bittering compounds from hops, enzymatic reactions involved in mashing beer, colloidal chemistry of haze formation, and microbiology of yeast and fermentation. Quantitative models will be applied to these processes based on fundamental chemical engineering principles from reaction kinetics, thermodynamics, transport phenomena, and colloid and interfacial science.
Prerequisite: Minimum grade of C- in CHBE424 and CHBE440; and permission of instructor.
Restriction: Must be in a major within the ENGR-Chemical & Biomolecular Engineering department; and permission of ENGR- & Biomolecular Engineering department.
Credit Only Granted for: CHBE493 or CHBE693.
Additional Information: Neither the students nor the instructor will be making or working with alcoholic beverages in the course.

CHBE494 Sustainable Separations and Carbon Capture (3 Credits)
Provides a comprehensive overview of sustainable separations and carbon dioxide capture using synthetic membranes and sorbents.
Prerequisite: Minimum grade of C- in CHBE424, CHBE426 and CHBE440; and permission of instructor.
Restriction: Must be in a major within the ENGR-Chemical & Biomolecular Engineering department; and must have permission of ENGR- & Biomolecular Engineering department.
Credit Only Granted for: CHBE494 or CHBE694.

CHBE495 Nanoparticle Aerosol Dynamics and Particle Technology (3 Credits)
NanoParticles (NA) (< 100 nm), and their science and technology play an important role in nature and industry. From air quality standards, nuclear reactor safety, inhalation therapy, workplace exposure, global climate change, to counterterrorism, aerosols play a central role in our environment. On the industrial side, NA plays an integral part of reinforcing fillers, pigments and catalysts, and the new emerging field of nanotechnology, they are the building blocks to new materials, which encompass, electronic, photonic and magnetic devices, and bio and chemical sensors.
Restriction: Must be in a major within the ENGR-Chemical & Biomolecular Engineering department; and permission of ENGR-Chemical & Biomolecular Engineering department.

CHBE496 Polymeric Materials: Structure, Property, and Processing (3 Credits)
An intermediate level treatment of structures of polymers. An introduction to mechanical properties and processing of polymeric materials. Emphasis will be on how to establish the structure-property relationship and on how to achieve such understanding via different characterization methods.
Prerequisite: ENMA300; and permission of ENGR-Materials Science & Engineering department.
Cross-listed with: ENMA496.
Credit Only Granted for: ENMA496 or CHBE496.

CHBE497 Protein Engineering (3 Credits)
This course will cover the fundamentals of protein engineering and its applications in medicine, chemical processes, and energy. Topics will include the structure and function of biological molecules, rational design and directed evolution, construction of protein and peptide libraries, protein screening platforms, methods for characterizing structure and function of biological molecules. Scientific literature will be used to highlight key discoveries and current work in protein engineering.
Prerequisite: BIOE120, CHBE302, and CHBE440; and permission of instructor.
Jointly offered with: CHBE697.
Credit Only Granted for: CHBE497, BIOE489R, ENCH 648P or CHBE697.

CHBE608 Research in Chemical Engineering (1 Credit)
Students gain experience in research through lab rotations and experience presenting their findings.
Restriction: Must be in the Chemical Engineering Doctoral or Master of Science program.
Repeatable to: 8 credits.

CHBE609 Graduate Seminar (1 Credit)
Seminar in Chemical and Biomolecular Engineering
Repeatable to: 4 credits.

CHBE610 Chemical Engineering Thermodynamics (3 Credits)
Advanced application of the general thermodynamic methods to chemical engineering problems. First and second law consequences; estimation and correlation of thermodynamic properties; phase and chemical reaction equilibria.
Prerequisite: CHBE301; and CHBE302. Or students who have taken courses with comparable content may contact the department.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: ENCH610 or CHBE610.
Formerly: ENCH610.

CHBE620 Methods of Engineering Analysis (3 Credits)
Application of selected mathematical techniques to the analysis and solution of engineering problems; included are the applications of matrices, vectors, tensors, differential equations, integral transforms, and probability methods to such problems as unsteady heat transfer, transient phenomena in mass transfer operations, stagewise processes, chemical reactors, process control, and nuclear reactor physics.
Prerequisite: MATH246 and CHBE250; or students who have taken courses with comparable content may contact the department.
Credit Only Granted for: ENCH620 or CHBE620.
Formerly: ENCH620.

CHBE630 Transport Phenomena (3 Credits)
Heat, mass and momentum transfer theory from the viewpoint of the basic transport equations. Steady and unsteady state; laminar and turbulent flow; boundary layer theory, mechanics of turbulent transport; with specific application to complex chemical engineering situations.
Prerequisite: CHBE422; and ENCH424. Or students who have taken courses with comparable content may contact the department.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: ENCH630 or CHBE630.
Formerly: ENCH630.

CHBE640 Advanced Chemical Reaction Kinetics (3 Credits)
The theory and application of chemical reaction kinetics to reactor design. Reaction rate theory; homogeneous batch and flow reactors; fundamentals of catalysis; design of heterogeneous flow reactors.
Prerequisite: CHBE440; or students who have taken courses with comparable content may contact the department.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: ENCH640 or CHBE640.
Formerly: ENCH640.

CHBE648 Special Problems in Chemical Engineering (1-12 Credits)
Research project under the direction of a faculty member.
Repeatable to: 12 credits.
Formerly: ENCH648.

CHBE651 Photovoltaics: Solar Energy (3 Credits)
The emphasis of the class is on developing a conceptual understanding of the device physics and manufacturing processes of crystalline and thin-film photovoltaic cells, and to develop elementary computational skills necessary to quantify solar cell efficiency. The class material includes detailed, system-level energy balances necessary to understand how solar energy fits into the complete energy generation, conversion, and storage picture. Quantitative comparisons of PV technology to solar chemical conversion processes and biofuels are made.
Jointly offered with: CHBE451.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE451 or CHBE651.

CHBE652 Introduction of Machine Learning in Chemical Engineering (3 Credits)
Introduction of data science and machine learning approaches to modern problems in chemical engineering and materials science. This course develops data science approaches, including their foundational mathematical and statistical basis, and applies these methods to data sets of limited size and precision. Methods for regression and clustering will be developed and applied, with an emphasis on validation and error quantification. Techniques that will be developed include linear and nonlinear regression, clustering and logistic regression, dimensionality reduction, unsupervised learning, and artificial neural networks. These methods will be applied to a range of engineering problems, including conducting polymers, stretchable conductors, organic synthesis, and quality control in manufacturing.
Recommended: Basic knowledge of chemical engineering, materials science, ordinary differential equations, and Python is desirable.
Jointly offered with: CHBE452.
Restriction: Permission of Department or Instructor.
Credit Only Granted for: CHBE452 or CHBE652.

CHBE670 Colloid and Interface Science (3 Credits)
Introduction to colloidal systems and interfacial science. Topics include preparation, stability and coagulation kinetics of colloidal suspensions. Introduction to DLVO theory, electrokinetic phenomena, colloidal aggregation, interfacial phenomena, double layer theory, surface chemistry. Discussion of interfacial thermodynamics and interfacial forces for solid-liquid interfaces. Applications to nanomaterial synthesis, nanomaterial and polymer self-assembly, protein-protein interactions, and protein aggregation will be discussed.
Jointly offered with: CHBE470.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: ENCH648F, CHBE470 or CHBE670.
Formerly: ENCH648F.

CHBE672 Control of Air Pollution Sources (3 Credits)
Sources and effects of air pollutants, regulatory trends, atmospheric dispersion models, fundamentals of two-phase flow as applied to air pollution and air pollution control systems, design of systems for control of gases and particulate matter.
Jointly offered with: CHBE472.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE472 or CHBE672.

CHBE673 Electrochemical Energy Engineering (3 Credits)
Basic electrochemical thermodynamics and kinetics, with emphasis on electrochemical techniques, fundamental principle and performance of batteries, and supercapacitors.
Jointly offered with: CHBE473.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE473 or CHBE673.

CHBE674 Biopharmaceutical Process Development and Manufacturing (3 Credits)
Covers the fundamental steps involved in process development and manufacturing of biopharmaceuticals. An overview of different classes of biopharmaceuticals as well as manufacturing requirements for clinical development and regulatory approval will be provided. In depth coverage of manufacturing steps including cell culture, purification and formulation as well as drug product manufacturing, analysis and stability will be covered. Scientific literature will be used to highlight current challenges and novel solutions in each step of the manufacturing process. Scale up considerations, GMP requirements and process economics will also be introduced.
Jointly offered with: CHBE474.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE474, BIOE489T, ENCH648D or CHBE674.
Formerly: ENCH648D.

CHBE676 Molecular Modeling Methods (3 Credits)
Statistical mechanics will be introduced to give the fundamental background for atomic to mesoscale molecular modeling. Classical atomic-level simulations methods (Monte Carlo and Molecular Dynamics) and the procedures to develop intra- and intermolecular potentials will be covered. This course will also discuss the theory and application of coarse-grained molecular simulations, mesoscale simulations and other modern simulation techniques. A broad range of applications will be included throughout the semester, e.g., phase behavior of small molecules, kinetics, and biophysics.
Jointly offered with: CHBE476.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE476 or CHBE676.

CHBE677 Mesoscopic and Nanoscale Thermodynamics (3 Credits)
New emerging technologies deal with bio-membrane and gene engineering, microreactor chemistry and microcapsule drug delivery, micro-fluids and porous media, nanoparticles and nanostructures, supercritical fluid extraction and artificial organs. Engineers often design processes where classical thermodynamics may be insufficient, e.g., strongly fluctuating and nanoscale systems, or dissipative systems under conditions far away from equilibrium.
Prerequisite: A prior course in classical thermodynamics.
Jointly offered with: CHBE477.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE477 or CHBE677.

CHBE680 Bionanotechnology: Physical Principles (3 Credits)
Physics at nano/micro scales. Biomolecular building blocks. Simplest biomolecular assembly: protein folding. Nanoscale intermolecular interactions important in biology. Protein-ligand binding. Protein higher-order assembly: filaments, networks. Protein filaments and motility. DNA, RNA and their assembly assisted by proteins. Viral capsid assembly. Lipid assembly into micelles, bilayers. Lipid-protein co-assembly in membranes. Lipid and polymer-based carriers useful in medicine. Antimicrobial therapies. Targeted cancer therapy. Ideal properties of nanocarriers in terms of size, charge, and surface chemistry.
Jointly offered with: CHBE480.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: ENCH648N, CHBE480 or CHBE680.
Formerly: ENCH648N.

CHBE681 Transport Phenomena in Small and Biological Systems (3 Credits)
Familiarize students with the fundamental physics and modeling of transport phenomena in small and biological systems, and their current scientific and engineering utilization in microfluidics, nanofluidics and biological systems.
Jointly offered with: CHBE481.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE481 or CHBE681.

CHBE684 Metabolic Pathway Engineering (3 Credits)
A focus on the analysis and engineering of metabolic pathways through (chemical) engineering principles, will be covered. Topics covered include: overview of biochemistry and metabolism; metabolic flux analysis and isotope labeling illustrated with examples from the recent scientific literature; technologies for engineering metabolic pathways; metabolic control analysis and pathway regulation; applications of metabolic engineering to synthesis of biofuels and therapeutics; specialized and related subjects such as protein engineering and synthetic biology.
Jointly offered with: CHBE484.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE484 or CHBE684.

CHBE686 Advanced Heterogeneous Catalysis for Energy Applications (3 Credits)
Introduction to heterogeneous catalytic science and technology for energy conversion and hydocarbon processing. Preparation and mechanistic characterization of catalyst systems, kinetics of catalyzed reactions, adsorption and diffusion influences in heterogenious reactions. An overview of heterogeneous catalysis in various energy-related applications, including petroleum refining, chemicals from biomass, valorization of shale gas, and CO2 utilization will be introduced.
Prerequisite: Minimum grade of C- in CHBE302, CHBE424, and CHBE440; and permission of instructor.
Jointly offered with: CHBE486.
Restriction: Permission of instructor.
Credit Only Granted for: CHBE486, ENCH686 or CHBE686.
Formerly: ENCH686.

CHBE690 Polymer Reaction Engineering (3 Credits)
Advanced topics in polymerization kinetics, reactor design and analysis; addition and step-growth polymerization; homogeneous and heterogeneous polymerization; photopolymerization; reactor dynamics; optimal operation and control of industrial polymerization reactors.
Prerequisite: ENCH640; or permission of instructor.
Credit Only Granted for: ENCH781 or CHBE690.
Formerly: ENCH781.

CHBE697 Protein Engineering (3 Credits)
Covers the fundamentals of protein engineering and its applications in medicine, chemical processes, and energy. Topics will include the structure and function of biological molecules, rational design and directed evolution, construction of protein and peptide libraries, protein screening platforms, methods for characterizing structure and function of biological molecules. Scientific literature will be used to highlight key discoveries and current work in protein engineering.
Jointly offered with: CHBE497.
Restriction: Permission of ENGR-Chemical & Biomolecular Engineering department.
Credit Only Granted for: CHBE497, BIOE489R, ENCH 648P or CHBE697.
Formerly: ENCH648P.

CHBE799 Master's Thesis Research (1-6 Credits)
Repeatable to: 18 credits.

CHBE898 Pre-Candidacy Research (1-8 Credits)
Repeatable to: 18 credits.

CHBE899 Doctoral Dissertation Research (1-8 Credits)
Repeatable to: 18 credits.