CHEMICAL AND BIOLOGICAL ENGINEERING (CBEN)

CBEN110. FUNDAMENTALS OF BIOLOGY I. 4.0 Semester Hrs.
Equivalent with BIOL110,
(I, II) Fundamentals of Biology with Laboratory I. This course will emphasize the fundamental concepts of biology and use illustrative examples and laboratory investigations that highlight the interface of biology with engineering. The focus will be on (1) the scientific method; (2) structural, molecular, and energetic basis of cellular activities; (3) mechanisms of storage and transfer of genetic information in biological organisms; (4) a laboratory 'toolbox' that will carry them forward in their laboratory-based courses. This core course in biology will be interdisciplinary in nature and will incorporate the major themes and mission of this school - earth, energy, and the environment. Lecture Hours: 3; Lab Hours: 3; Semester Hours: 4.
Course Learning Outcomes

- Same as BIOL110

CBEN120. FUNDAMENTALS OF BIOLOGY II. 4.0 Semester Hrs.
Equivalent with CBEN323,
This is the continuation of Fundamentals of Biology I. Emphasis in the second semester is placed on an examination of organisms as the products of evolution and the diversity of life forms. Special attention will be given to how form fits function in animals and plants and the potential for biomimetic applications. Prerequisite: CBEN110. Fundamentals of Biology I or equivalent. 3 hours lecture; 3 hours laboratory; 4 semester hours.
Course Learning Outcomes

- 1. Describe and explain the processes and patterns of evolution, including mutation, variation, and natural selection.
- 2. Describe and explain the properties common within the three domains of life and the innovations that arose in evolutionary time as organisms diversified and adapted to terrestrial environments.
- 3. Use illustrative examples from key animal and plant physiological systems to explain how form fits function in the context of homeostasis and intercellular signaling, development and reproduction, resource acquisition and transport, and to discuss biomimetic and engineering applications of these biological concepts.
- 4. Explain and use the key principles of the scientific process to assess and design experiments.
- 5. Evaluate the credibility of scientific information from various sources.
- 6. Utilize instrumentation and methods for data acquisition and analysis, including tissue preparation for microscopy, dissection and tissue culture.

CBEN198. SPECIAL TOPICS. 6.0 Semester Hrs.
Topical courses in chemical engineering of special interest. Prerequisite: none; 1 to 6 semester hours. Repeatable for credit under different titles.

CBEN199. INDEPENDENT STUDY. 1-6 Semester Hr.
Individual research or special problem projects. Topics, content, and credit hours to be agreed upon by student and supervising faculty member. Prerequisite: submission of ?Independent Study? form to CSM Registrar. 1 to 6 semester hours. Repeatable for credit.

CBEN200. COMPUTATIONAL METHODS IN CHEMICAL ENGINEERING. 3.0 Semester Hrs.
Fundamentals of mathematical methods and computer programming as applied to the solution of chemical engineering problems. Introduction to computational methods and algorithm development and implementation. 3 hours lecture; 3 semester hours. Prerequisite: MATH112. Co-requisite: CBEN210.

CBEN201. MATERIAL AND ENERGY BALANCES. 3.0 Semester Hrs.
Equivalent with CHEN201,
Introduction to the formulation and solution of material and energy balances on chemical processes. Establishes the engineering approach to problem solving, the relations between known and unknown process variables, and appropriate computational methods. 3 hours lecture; 3 semester hours. Prerequisite: CHGN122. Co-requisite: CBEN210, CBEN200, MATH213, MATH225.

CBEN202. CHEMICAL PROCESS PRINCIPLES LABORATORY. 1.0 Semester Hr.
Laboratory measurements dealing with the first and second laws of thermodynamics, calculation and analysis of experimental results, professional report writing. Introduction to computer-aided process simulation. 3 hours lab; 1 semester hour. Co-requisite: CBEN210, CBEN201, MATH225, EDNS251.

CBEN210. INTRO TO THERMODYNAMICS. 3.0 Semester Hrs.
Introduction to the fundamental principles of classical engineering thermodynamics. Application of mass and energy balances to closed and open systems including systems undergoing transient processes. Entropy generation and the second law of thermodynamics for closed and open systems. Introduction to phase equilibrium and chemical reaction equilibria. Ideal solution behavior. May not also receive credit for CHGN209, MEGN261, or GEGN330. Prerequisite: CHGN121, CHGN122, MATH111. Co-requisite: MATH112, PHGN100.

CBEN250. INTRODUCTION TO CHEMICAL ENGINEERING ANALYSIS AND DESIGN. 3.0 Semester Hrs.
Introduction to chemical process industries and how analysis and design concepts guide the development of new processes and products. Use of simple mathematical models to describe the performance of common process building blocks including pumps, heat exchangers, chemical reactors, and separators. Prerequisites: Concurrent enrollment in CBEN210. 3 hours lecture; 3 semester hours.

CBEN298. SPECIAL TOPICS. 1-6 Semester Hr.
Topical courses in chemical engineering of special interest. Prerequisite: none; 1 to 6 semester hours. Repeatable for credit under different titles.

CBEN299. INDEPENDENT STUDY. 1-6 Semester Hr.
Individual research or special problem projects. Topics, content, and credit hours to be agreed upon by student and supervising faculty member. Prerequisite: submission of ?Independent Study? form to CSM Registrar. 1 to 6 semester hours. Repeatable for credit.

CBEN304. ANATOMY AND PHYSIOLOGY. 3.0 Semester Hrs.
Equivalent with CBEN404,
This course will cover the basics of human anatomy and physiology of the cardiovascular system and blood, the immune system, the respiratory system, the digestive system, the endocrine system, the urinary system and the reproductive system. We will discuss the gross and microscopic anatomy and the physiology of these major systems. Where possible, we will integrate discussions of disease processes and introduce biomedical engineering concepts and problems. Check with department

for semester(s) offered. 3 hours lecture; 3 semester hours. Prerequisite: General Biology I.

CBEN305. ANATOMY AND PHYSIOLOGY LAB. 1.0 Semester Hr.
Equivalent with CBEN405,
In this course we explore the basic concepts of human anatomy and physiology using simulations of the physiology and a virtual human dissector program. These are supplemented as needed with animations, pictures and movies of cadaver dissection to provide the student with a practical experience discovering principles and structures associated with the anatomy and physiology. Co-requisite: CBEN404.

CBEN307. FLUID MECHANICS. 3.0 Semester Hrs.
This course covers theory and application of momentum transfer and fluid flow. Fundamentals of microscopic phenomena and application to macroscopic systems are addressed. Course work also includes computational fluid dynamics. 3 hours lecture; 3 semester hours. Prerequisite: MATH225, grade of C- or better in CBEN201.

CBEN308. HEAT TRANSFER. 3.0 Semester Hrs.
This course covers theory and applications of energy transfer: conduction, convection, and radiation. Fundamentals of microscopic phenomena and their application to macroscopic systems are addressed. Course work also includes application of relevant numerical methods to solve heat transfer problems. 3 hours lecture; 3 semester hours. Prerequisite: MATH225, grade of C- or better in CBEN307.

CBEN310. INTRODUCTION TO BIOMEDICAL ENGINEERING. 3.0 Semester Hrs.
Introduction to the field of Biomedical Engineering including biomolecular, cellular, and physiological principles, and areas of specialty including biomolecular engineering, biomaterials, biomechanics, bioinstrumentation and bioimaging. Prerequisite: CBEN110, MATH112.

CBEN311. INTRODUCTION TO NEUROSCIENCE. 3.0 Semester Hrs.
This course is the general overview of brain anatomy, physiology, and function. It includes perception, motor, language, behavior, and executive function. This course will review what happens with injury and abnormalities of thought. It will discuss the overview of brain development throughout one's lifespan. Prerequisite: CBEN110, CHGN121, CHGN122, PHGN100, PHGN200.

CBEN312. UNIT OPERATIONS LABORATORY. 3.0 Semester Hrs.
Unit Operations Laboratory. This course covers principles of mass, energy, and momentum transport as applied to laboratory-scale processing equipment. Written and oral communications skills, teamwork, and critical thinking are emphasized. 9 hours lab; 3 semester hours. Prerequisite: CBEN201, CBEN202 OR CBEN200, CBEN307, CBEN308 OR CBEN314, CBEN357, CBEN375.

CBEN313. UNIT OPERATIONS LABORATORY. 3.0 Semester Hrs.
Unit Operations Laboratory. This course covers principles of mass, energy, and momentum transport as applied to laboratory-scale processing equipment. Written and oral communications skills, teamwork, and critical thinking are emphasized. 9 hours lab; 3 semester hours. Prerequisite: CBEN201, CBEN202 OR CBEN200, CBEN307, CBEN308 OR CBEN314, CBEN357, CBEN375.

CBEN314. CHEMICAL ENGINEERING HEAT AND MASS TRANSFER. 4.0 Semester Hrs.
This course covers theory and applications of energy transfer: conduction, convection, and radiation and mass transfer: diffusion and convection. Fundamentals of microscopic phenomena and their application to macroscopic systems are addressed. Course work also includes application of relevant numerical methods to solve heat and mass transfer problems. Prerequisite: MATH225, CBEN307 with a grade of C- or better. Co-requisite: CBEN200.

Course Learning Outcomes

- Define the basic concepts of heat transfer (e.g. heat flow, heat flux, temperature difference).
- Derive microscopic mass and energy balances for chemical engineering systems.
- Apply Fourier’s law for heat conduction to systems with and without heat source terms and for steady-state and transient operation.
- Solve heat conduction problems involving composite media, standard geometries, and various boundary conditions.
- Apply thermal energy balances together with Newton’s Law of Cooling to convective heat transfer
- Select and apply appropriate convective heat transfer correlations to internal and external flows including boiling and condensation
- Size heat exchangers using the LMTD or NTU method and conduct heat transfer performance calculations using energy balances including identifying controlling resistances for heat exchangers
- Use radiative heat transfer coefficients based on Planck's and Stefan-Boltzmann's laws of radiation for engineering calculations.
- Apply species balances together with Fick’s Law to steady-state and transient diffusion.
- Apply species balances together with relevant rate equations to convective mass transfer.
- Recognize the differences between diffusive and convective mass transfer including diffusion coefficients and mass transfer coefficients. Use correlations to estimate mass transfer coefficients and diffusion coefficients for specified systems and use these to calculate such macroscopic quantities as component fluxes.
- Design continuous mass transfer equipment and analyze its operation.

CBEN315. INTRODUCTION TO ELECTROCHEMICAL ENGINEERING. 3.0 Semester Hrs.
Introduction to the field of Electrochemical Engineering including basic electrochemical principles, electrode kinetics, ionic conduction, as applied to common devices such as fuel cells, electrolyzers, redox flow cells and batteries. 3 hours lecture; 3 semester hours. Prerequisite: CBEN210.
Course Learning Outcomes

- Describe the various principles that are important to Electrochemical engineering, including electrode kinetics and electrocatalysis, double layer capacitance, mass transfer, ionic conduction, Pourbaix diagrams and durability issues, and materials and systems limitations.
- Define the specific areas of specialty in Electrochemical engineering and explain their basic principles (Fuel Cells, Electrolyzers, Batteries, Redox Flow Batteries, Super Capacitors).

CBEN320. CELL BIOLOGY AND PHYSIOLOGY. 3.0 Semester Hrs.
Equivalent with CBEN410,
An introduction to the morphological, biochemical, and biophysical properties of cells and their significance in the life processes. Prerequisite: General Biology I or equivalent.

CBEN321. INTRO TO GENETICS. 4.0 Semester Hrs.
A study of the mechanisms by which biological information is encoded, stored, and transmitted, including Mendelian genetics, molecular genetics, chromosome structure and rearrangement, cytogenetics, and population genetics. 3 hours lecture, 3 hours laboratory; 4 semester hours. Prerequisite: General biology I or equivalent.

CBEN322. BIOLOGICAL PSYCHOLOGY. 3.0 Semester Hrs.
This course relates the hard sciences of the brain and neuroscience to the psychology of human behavior. It covers such topics as decision making, learning, the brain's anatomy and physiology, psychopathology, addiction, the senses, sexuality, and brainwashing. It addresses the topics covered on the psychology section of the MCAT examination. Prerequisite: CBEN110, CHGN122, PHGN200.
Course Learning Outcomes

- Identify the major brain areas and their function.
- Identify microscopic anatomy of cortical layers and columns.
- Describe action potentials, nerve impulses, and networking of brain cells.
- Identify Limbic system components and their part in emotional memory.
- Describe normal and abnormal human behavior.
- Discuss short-term versus long-term memory.
- Describe how explicit and implicit memory work and the differences.
- Describe/compare modern theories of neuroscience and psychology.
- Be able to comprehend current literature (i.e. articles/books) in neuroscience and psychology.
- Describe life span development of the brain, behavior, and social interactions.
- Describe how the brain handles emotion, aggression, and stress.
- Combine the above concepts to discuss the biological foundations of behavior.

CBEN323. GENERAL BIOLOGY II LABORATORY. 1.0 Semester Hr.
Equivalent with CBEN120,
This Course provides students with laboratory exercises that complement lectures given in CBEN303, the second semester introductory course in Biology. Emphasis is placed on an examination of organisms as the products of evolution. The diversity of life forms will be explored. Special attention will be given to the vertebrate body (organs, tissues and systems) and how it functions. Co-requisite or 3 hours laboratory; 1 semester hour. Prerequisite: CBEN303 or equivalent.

CBEN324. INTRODUCTION TO BREWING SCIENCE. 3.0 Semester Hrs.
Introduction to the field of Brewing Science including an overview of ingredients and the brewing process, the biochemistry of brewing, commercial brewing, quality control, and the economics of the brewing industry. Students will malt grain, brew their own beer, and analyze with modern analytical equipment. 2 hours lecture; 3 hours lab; 3 semester hours. Prerequisites: CBEN110; Student must be at least 21 years of age at beginning of semester.
Course Learning Outcomes

- Name traditional beer ingredients and the role of each ingredient in the finished product
- Describe the brewing process and the purpose of each step in the brewing process
- Describe the biochemistry of malting, brewing process, fermentation, and beer aging
- Name and describe alternatives to traditional ingredients, process, and fermentation
- Design (with detailed notes) a modern brewing facility
- Describe important characteristics of beer appearance, aroma, flavor, mouthfeel, & stability
- Describe how brewing ingredients, process, and fermentation can be manipulated to affect important beer characteristics
- Formulate a recipe for a BJCP beer style and perform an economic analysis on the recipe in the system designed in 5), above
- Discuss important current topics in brewing

CBEN325. MCAT REVIEW. 3.0 Semester Hrs.
The MCAT Review course is specifically for preparation of the Medical College Admissions Test [MCAT]. It will look at test taking skills, the information required to study for the MCAT, and will go over in detail the psychology information and the critical analysis and reading skills sections of the exam as well as doing practice exams. 3 hours lecture; 3 semester hours. Prerequisite: CBEN110, PHGN200, CHGN222. Co-requisite: CBEN120.
Course Learning Outcomes

- Describe test taking skills.
- Schedule test preparation time over several months.
- Name types of subjects in the MCAT exam.
- Describe important strategies for major testing and exams.
- Use representative concepts from the basic sciences for a more in depth comprehension.
- Describe critical analysis in reading passages.
- Provide specific examples of critical analysis.
- Apply test taking skills to the actual testing format.
- Contrast and compare theories through reading analysis.

CBEN340. COOPERATIVE EDUCATION. 1-3 Semester Hr.
Cooperative work/education experience involving employment of a chemical engineering nature in an internship spanning at least one academic semester. Prerequisite: none. 1 to 3 semester hours. Repeatable to a maximum of 6 hours.

CBEN350. HONORS UNDERGRADUATE RESEARCH. 1-3 Semester Hr.
Scholarly research of an independent nature. Prerequisite: Junior standing. 1 to 3 semester hours.

CBEN351. HONORS UNDERGRADUATE RESEARCH. 1-3 Semester Hr.
Scholarly research of an independent nature. Prerequisite: junior standing. 1 to 3 semester hours.

CBEN357. CHEMICAL ENGINEERING THERMODYNAMICS. 3.0 Semester Hrs.
Introduction to non-ideal behavior in thermodynamic systems and their applications. Phase and reaction equilibria are emphasized. Relevant aspects of computer-aided process simulation are incorporated. 3 hours lecture; 3 semester hours. Prerequisite: CBEN210 (or equivalent), MATH225, grade of C- or better in CBEN201.

CBEN358. CHEMICAL ENGINEERING THERMODYNAMICS LABORATORY. 1.0 Semester Hr.
This course includes hands-on laboratory measurements of physical data from experiments based on the principles of chemical engineering thermodynamics. Methods and concepts explored include calculation and analysis of physical properties, phase equilibria, and reaction equilibria and the application of these concepts in chemical engineering. 3 hours lab; 1 semester hour. Prerequisite: CBEN200 and CBEN210 or CHGN209.
Course Learning Outcomes

- Effectively analyze experimental data and generate summary reports of simulation results. This may include solving complicated system of equations or use of optimization techniques.
- Given an experimental objective, design a simple configuration to measure the required data and determine what analysis of the data will be required to obtain the desired information. This includes figuring out what equations need to be applied to the experimentally measured data BEFORE the data is measured. The wet labs may include, as part of the evaluation, building the system into an Aspen model as a means to validate lab results or test the validity of thermodynamic models within Aspen.
- Given a set of measured data, fully analyze the data set and use it to determine associated thermodynamic parameters.

CBEN360. BIOPROCESS ENGINEERING. 3.0 Semester Hrs.
The analysis and design of microbial reactions and biochemical unit operations, including processes used in conjunction with bioreactors, are investigated in this course. Industrial enzyme technologies are developed and explored. A strong focus is given to the basic processes for producing fermentation products and biofuels. Biochemical systems for organic oxidation and fermentation and inorganic oxidation and reduction are presented. Computer-aided process simulation is incorporated. 3 hours lecture; 3 semester hours. Prerequisites: CHGN428, CBEN201, CBEN358.
Course Learning Outcomes

- Describe the growth and decay manipulation of yeast and bacteria, and know what basic cell types are used in / found in various “bioprocess” applications.
- Describe kinetic mechanisms of cell growth and decay, and where appropriate write mathematical models describing the growth processes.
- Draw chemical structures of biological molecules including fats, lipids, amino acids, and proteins.
- Define enzyme and describe mechanistic models for enzyme function; demonstrate a comprehension of Michaelis-Menten and Quasi Steady-State Kinetics by working applied quantitative problems, including aspects of enzyme inhibition. Describe industrial uses of enzyme technologies.
- Summarize and apply the basics of a wide range of “bioprocess” principles such as those of metabolism, biochemical conversion, thermochemical conversion, and direct chemical conversion.
- Describe the basic processes for producing biofuels, fermentation products, and bio-pharmaceuticals by drawing representative process flow diagrams listing the required unit operations.
- Interview successfully for a job in the biochemical process industries by conversing intelligently with the interviewer about technical aspects of biological sciences and biochemical engineering.
- Collect and analyze data for biological processes such as extraction, enzyme kinetics, and aeration.

CBEN365. INTRODUCTION TO CHEMICAL ENGINEERING PRACTICE. 3.0 Semester Hrs.
Builds on the design process introduced in Design EPICS I, which focuses on open-ended problem solving approached in an integrated teamwork environment, and initial technical content specific to the Chemical Engineering degree program to solve a range of chemical process engineering problems. Technical content necessary for process analysis and design activity is presented. This course emphasizes steady-state design in areas such as fuels, food sciences, chemicals, and pharmaceuticals, wherein creative and critical thinking skills are necessary. Projects may involve computer-based optimization to obtain a solution. 3 hours lecture; 3 semester hours. Prerequisite: EDNS151 or EDNS155, CBEN 200, CBEN201.
Course Learning Outcomes

- Apply creative and critical thinking skills to chemical engineering projects with an emphasis on process/system designs and data analysis, demonstrated via classroom activities and presentations and through content presented in design reports.
- Analyze design alternatives for a chemical system, identifying best options based on socio-technical-economic design criteria as well as core engineering design criteria, with evidence that supports an optimal design approach, validated using comparative assessment tools (e.g., software tools and design heuristics).
- Actively contribute to design teams, demonstrating commitment to solving open-ended problems through appropriate application of course content/material and incorporating a range of resource management strategies.
- Prepare communication material (presentations and reports) that clearly support engineering design by communicating the technical, economic, and social feasibility of an engineering strategy.

CBEN368. INTRODUCTION TO UNDERGRADUATE RESEARCH. 1.0 Semester Hr.
Introduction to Undergraduate Research. This course introduces research methods and provides a survey of the various fields in which CBE faculty conduct research. Topics such as how to conduct literature searches, critically reading and analyzing research articles, ethics, lab safety, and how to write papers are addressed. Prerequisite: None.

CBEN372. INTRODUCTION TO BIOENERGY. 3.0 Semester Hrs.
In this course the student will gain an understanding about using biological sources and processes for energy uses, both electricity and fuels. There is an emphasis on using chemical engineering principles and tools to aid in the analysis of these bioenergy systems. Specific technologies will be addressed that have historical use and future potential, such as biochemical conversion routes to biofuels (chemical vs. enzymatic hydrolysis followed by fermentation), gasification followed by Fischer-Tropsch synthesis, application of anaerobic digestion, and others. Since products are to be used as energy carriers there will an emphasis on the energy efficiency of transformations and comparing the efficiencies of competing transformation pathways. Prerequisite: CBEN201, CBEN210.
Course Learning Outcomes

- Summarize & discuss the science, engineering, and business fundamentals associated with the bioenergy & biofuels industries
- Analyze the bioenergy industry applying science & engineering fundamentals to feedstocks, conversion technologies, & potential biorefinery configurations
- Specifically apply chemical engineering techniques & process simulation software to analyze bioenergy and biofuel processes

CBEN375. CHEMICAL ENGINEERING SEPARATIONS. 3.0 Semester Hrs.
This course covers fundamentals of stage-wise and diffusional mass transport with applications to chemical engineering systems and processes. Relevant aspects of computer-aided process simulation and computational methods are incorporated. 3 hours lecture; 3 semester hours. Prerequisite: grade of C- or better in CBEN357.

CBEN398. SPECIAL TOPICS. 1-6 Semester Hr.
Topical courses in chemical engineering of special interest. Prerequisite: none; 1 to 6 semester hours. Repeatable for credit under different titles.

CBEN399. INDEPENDENT STUDY. 1-6 Semester Hr.
Individual research or special problem projects. Topics, content, and credit hours to be agreed upon by student and supervising faculty member. Prerequisite: submission of ?Independent Study? form to CSM Registrar. 1 to 6 semester hours. Repeatable for credit.

CBEN401. PROCESS OPTIMIZATION. 3.0 Semester Hrs.
This course introduces skills and knowledge required to develop conceptual designs of new processes and tools to analyze troubleshoot, and optimize existing processes. Prerequisite: CBEN201, CBEN308 or CBEN314, CBEN307, CBEN357, CBEN375, CBEN402.

CBEN402. CHEMICAL ENGINEERING DESIGN. 3.0 Semester Hrs.
This course covers simulation, synthesis, analysis, evaluation, as well as costing and economic evaluation of chemical processes. Computer-aided process simulation to plant and process design is applied. Prerequisite: CBEN307, CBEN308 or CBEN 314, CBEN357, CBEN375. Co-requisite: CBEN358, CBEN418.

CBEN403. PROCESS DYNAMICS AND CONTROL. 3.0 Semester Hrs.
Mathematical modeling and analysis of transient systems. Applications of control theory to response of dynamic chemical engineering systems and processes. 3 hours lecture; 3 semester hours.Co-requisites: CBEN314 or CBEN308, CBEN375. Prerequisites: CBEN201, CBEN307, MATH225.

CBEN408. NATURAL GAS PROCESSING. 3.0 Semester Hrs.
Application of chemical engineering principles to the processing of natural gas. Emphasis on using thermodynamics and mass transfer operations to analyze existing plants. Relevant aspects of computer-aided process simulation. Prerequisite: CHGN221, CBEN308 or CBEN314, CBEN375.

CBEN409. PETROLEUM PROCESSES. 3.0 Semester Hrs.
Application of chemical engineering principles to petroleum refining. Thermodynamics and reaction engineering of complex hydro carbon systems. Relevant aspects of computer-aided process simulation for complex mixtures. 3 hours lecture; 3 semester hours. Prerequisite: CHGN221, CBEN375.

CBEN411. NEUROSCIENCE, MEMORY, AND LEARNING. 3.0 Semester Hrs.
Equivalent with CBEN511,
This course relates the hard sciences of the brain and neuroscience to memory encoding and current learning theories. 3 hours lecture, 3 semester hours. Prerequisites: CBEN110, CBEN120, CHGN221, CHGN222, PHGN100, PHGN200.

CBEN412. INTRODUCTION TO PHARMACOLOGY. 3.0 Semester Hrs.
This course introduces the concepts of pharmacokinetics and biopharmaceuticals. It will discuss the delivery systems for pharmaceuticals and how they change with disease states. It will cover the modeling of drug delivery, absorption, excretion, and accumulation. The course will cover the different modeling systems for drug delivery and transport. 3 hours lecture; 3 semester hours. Prerequisite: CBEN110, CBEN120, CHGN121, CHGN122.

CBEN413. QUANTITATIVE HUMAN BIOLOGY. 3.0 Semester Hrs.
This course examines the bioelectric implications of the brain, heart, and muscles from a biomedical engineering view point. The course covers human brain, heart, and muscle anatomy as well as the devices currently in use to overcome abnormalities in function. Prerequisite: CBEN 110, CBEN 120.
Course Learning Outcomes

- 1) Describe the mechanisms that make a membrane excitable.
- 2) Order the steps in the production and maintenance of a membrane potential
- 3) Name and define fundamental aspects of brain, heart, and muscle anatomy.
- 4) Describe important roles of the electric components in the brain, heart, and muscle
- 5) Using current monitoring devices, illustrate & compare brain, heart, and muscle recordings.
- 6) Describe critical pathophysiology of the bioelectric systems.
- 7) Provide specific examples of current bioelectrical devices and what they do.
- 8) Describe critical advances in bioelectrical engineering.
- 9) Relate the imaging modalities for the brain and heart as a process of imaging function.
- 10) Describe homeostasis of the bioelectrical pathways by medical intervention.
- 11) Describe how the organs store energy and change the chemical energy into electrical

CBEN414. CHEMICAL PROCESS SAFETY. 1.0 Semester Hr.
This course considers all aspects of chemical process safety and loss prevention. Students are trained for the identification of potential hazards and hazardous conditions associated with the processes and equipment involved in the chemical process industries, and methods of predicting the possible severity of these hazards and presenting, controlling or mitigating them. Quantitative engineering analysis training delivered by each of the CHEN core courses is applied: applications of mass and energy balances, fluid mechanics of liquid, gas, and two-phase flows, heat transfer, the conservation of energy, mass transfer, diffusion and dispersion under highly variable conditions, reaction kinetics, process control, and statistical analysis. 1 hour lecture; 1 semester hour. Prerequisite: CBEN375. Corequisite: CBEN418.
Course Learning Outcomes

- Students will understand the professional and ethical elements of an outstanding safety program.
- Students will be familiar with government agencies, regulatory bodies, codes, and standards that govern the global, societal, and environmental impact of plant design projects.
- Students will understand how unsound science or unethical behavior had a negative impact on society.
- Students will be able to perform quantitative engineering analysis based upon the applications of mass and energy balance, fluid mechanics of liquid, gas, and two-phase flows, heat transfer and the conservation of energy, mass transfer, diffusion and dispersion under highly variable conditions, reaction kinetics, process control, and statistics.
- Students will be able to work effectively in teams and develop problem solving skills. Each team will prepare and present a professional project report.

CBEN415. POLYMER SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.
Equivalent with CHGN430,MLGN530,
Chemistry and thermodynamics of polymers and polymer solutions. Reaction engineering of polymerization. Characterization techniques based on solution properties. Materials science of polymers in varying physical states. Processing operations for polymeric materials and use in

separations. 3 hours lecture; 3 semester hours. Prerequisite: CHGN222 Co-requisite: CBEN357.

CBEN416. POLYMER ENGINEERING AND TECHNOLOGY. 3.0 Semester Hrs.

Polymer fluid mechanics, polymer rheological response, and polymer shape forming. Definition and measure ment of material properties. Interrelationships between response functions and correlation of data and material response. Theoretical approaches for prediction of polymer properties. Processing operations for polymeric materials; melt and flow instabilities. Prerequisite: CBEN307, MATH225. 3 hours lecture; 3 semester hours.

CBEN418. KINETICS AND REACTION ENGINEERING. 3.0 Semester Hrs.

This course emphasizes applications of the fundamentals of thermodynamics, physical chemistry, organic chemistry, and material and energy balances to the engineering of reactive processes. Key topics include reactor design, acquisition and analysis of rate data, and heterogeneous catalysis. Computational methods as related to reactor and reaction modeling are incorporated. Prerequisite: CBEN308 or CBEN314, CBEN357, MATH225, CHGN221. Co-requisite: CHGN351.

CBEN420. MATHEMATICAL METHODS IN CHEMICAL ENGINEERING. 3.0 Semester Hrs.

Engineering applications of data analytics and numerical methods, including numerical integration/differentiation, systems of algebraic equations, linear algebra, and ordinary/partial differential equations. Practical implementation in modern programming languages and computational environments discussed. Emphasis on chemical engineering problems that cannot be solved by analytical methods. 3 hours lecture; 3 semester hours. Prerequisite: MATH225, CHGN209 or CBEN210, CBEN307, CBEN357.

CBEN422. CHEMICAL ENGINEERING FLOW ASSURANCE. 3.0 Semester Hrs.

Chemical Engineering Flow Assurance will include the principles of the application of thermodynamics and mesocopic and microscopic tools that can be applied to the production of oil field fluids, including mitigation strategies for solids, including gas hydrates, waxes, and asphaltenes. 3 hours lecture; 3 semester hours. Prerequisite: CBEN357.

Course Learning Outcomes

- 1. Demonstrate an understanding of the chemistry and physical properties of oil field production fluids and solids.
- 2. Demonstrate an understanding of the thermodynamics of oil field fluids and solids, including gas hydrates, waxes, and asphaltenes phase equilibria.
- 3. Be able to apply phase equlibrium models to predict the phase equilibria behavior of complex fluids, as well as gas solubility in water/oil systems.
- 4. Demonstrate an understanding of the macroscopic, mesoscopic, and microscopic tools that can be applied to study oil field processing methods, including the control of hydrates, waxes, asphaltenes, scale.
- 5. Demonstrate an understanding of the appropriate chemical treatments and compatibility of the treatment processes for flow assurance.
- 6. Demonstrate an understanding of the key physical chemistry concepts of flow assurance.
- 7. Demonstrate an understanding of the key concepts of industrial gas transportation and storage.

CBEN424. COMPUTER-AIDED PROCESS SIMULATION. 3.0 Semester Hrs.

Advanced concepts in computer-aided process simulation are covered. Topics include optimization, heat exchanger networks, data regression analysis, and separations systems. Use of industry-standard process simulation software (Aspen Plus) is stressed. 3 hours lecture; 3 semester hours. Prerequisite: CBEN314 or CBEN308, CBEN357, and CBEN375 Co-requisite: CBEN402 and CBEN418.

Course Learning Outcomes

- Modeling Unit Operations
- Modeling Processes Including Recycle Loops
- Process Optimization

CBEN426. ADVANCED FUNCTIONAL POROUS MATERIALS. 3.0 Semester Hrs.

Nanomaterials synthesis, hierarchically ordered porous materials, functional applications, catalysis, separations, adsorption Prerequisite: CHGN122. Co-requisite: CHGN351.

Course Learning Outcomes

CBEN430. TRANSPORT PHENOMENA. 3.0 Semester Hrs.

This course covers theory and applications of momentum, energy, and mass transfer based on microscopic control volumes. Analytical and numerical solution methods are employed in this course. 3 hours lecture; 3 semester hours. Prerequisite: CBEN307, CBEN308 or CBEN314, CBEN357, CBEN375, MATH225.

CBEN431. IMMUNOLOGY FOR ENGINEERS AND SCIENTISTS. 3.0 Semester Hrs.

This course introduces the basic concepts of immunology and their applications in engineering and science. We will discuss the molecular, biochemical and cellular aspects of the immune system including structure and function of the innate and acquired immune systems. Building on this, we will discuss the immune response to infectious agents and the material science of introduced implants and materials such as heart valves, artificial joints, organ transplants and lenses. We will also discuss the role of the immune system in cancer, allergies, immune deficiencies, vaccination and other applications such as immunoassay and flow cytometry. Prerequisite: CBEN110.

CBEN432. TRANSPORT PHENOMENA IN BIOLOGICAL SYSTEMS. 3.0 Semester Hrs.

The goal of this course is to develop and analyze models of biological transport and reaction processes. We will apply the principles of mass, momentum, and energy conservation to describe mechanisms of physiology and pathology. We will explore the applications of transport phenomena in the design of drug delivery systems, engineered tissues, and biomedical diagnostics with an emphasis on the barriers to molecular transport in cardiovascular disease and cancer. Prerequisite: CBEN307.

CBEN435. INTERDISCIPLINARY MICROELECTRONICS. 3.0 Semester Hrs.

Equivalent with MLGN535,PHGN435,PHGN535,

(II) Application of science and engineering principles to the design, fabrication, and testing of microelectronic devices. Emphasis on specific unit operations and the interrelation among processing steps. Prerequisites: Senior standing in PHGN, CBEN, MTGN, or EGGN. Due to lab, space the enrollment is limited to 20 students. 1.5 hours lecture, 4 hours lab; 3 semester hours.

CBEN440. MOLECULAR PERSPECTIVES IN CHEMICAL ENGINEERING. 3.0 Semester Hrs.

Applications of statistical and quantum mechanics to understanding and prediction of equilibrium and transport properties and processes.

Relations between microscopic properties of materials and systems to macroscopic behavior. 3 hours lecture; 3 semester hours. Prerequisite: CBEN307, CBEN308 or CBEN314, CBEN357, CBEN375, CHGN351 and CHGN353, CHGN221 and CHGN222, MATH225.

CBEN450. HONORS UNDERGRADUATE RESEARCH. 1-3 Semester Hr.
Scholarly research of an independent nature. Prerequisite: senior standing. 1 to 3 semester hours.

CBEN451. HONORS UNDERGRADUATE RESEARCH. 1-3 Semester Hr.
Scholarly research of an independent nature. Prerequisite: senior standing. 1 to 3 semester hours.

CBEN454. APPLIED BIOINFORMATICS. 3.0 Semester Hrs.
In this course we will discuss the concepts and tools of bioinformatics. The molecular biology of genomics and proteomics will be presented and the techniques for collecting, storing, retrieving and processing such data will be discussed. Topics include analyzing DNA, RNA and protein sequences, gene recognition, gene expression, protein structure prediction, modeling evolution, utilizing BLAST and other online tools for the exploration of genome, proteome and other available databases. In parallel, there will be an introduction to the PERL programming language. Practical applications to biological research and disease will be presented and students given opportunities to use the tools discussed. 3 hour lecture; 3 semester hours. Prerequisites: General Biology [BIOL110].

CBEN455. INTERNATIONAL GENETIC ENGINEERED MACHINE SEMINAR. 1.0 Semester Hr.
iGEM allows for a hands-on experience in the emerging frontier of synthetic biology and genetic engineering while promoting an entrepreneurial spirit as students engage in teams with all aspects of the engineering design process. CBEN455 is a 1-credit hour seminar course that supports the Mines iGEM students in this process through discussions of previous iGEM projects, initial brainstorming of project ideas, discussion of experimental design, training in lab safety and standard molecular biology protocols and team dynamics. The design process starts with stakeholder engagement, and student identification of a problem they wish to solve using synthetic biology. A team will go through the design build test cycle multiple times in preparation for a culminating public presentation at an international symposium. Projects cover frontiers of science and engineering, such as new biochemical production, new materials, environmental projects (e.g., promoting enzymatic degradation of PET plastics), analysis, and health innovations.

Course Learning Outcomes

- Analysis of previous iGEM projects
- Design new iGEM team projects based off literature reviews
- Employ molecular biology lab techniques to answer experimental questions.
- Create a positive team environment that promotes iGEM project success

CBEN460. BIOCHEMICAL PROCESS ENGINEERING. 3.0 Semester Hrs.
The analysis and design of microbial reactions and biochemical unit operations, including processes used in conjunction with bioreactors, are investigated in this course. Industrial enzyme technologies are developed and explored. A strong focus is given to the basic processes for producing fermentation products and biofuels. Biochemical systems for organic oxidation and fermentation and inorganic oxidation and reduction are presented. 3 hours lecture; 3 semester hours Prerequisite: CBEN201, CBEN358, CHGN428.

CBEN461. BIOCHEMICAL PROCESS ENGINEERING LABORATORY. 1.0 Semester Hr.
This course emphasizes bio-based product preparation, laboratory measurement, and calculation and analysis of bioprocesses including fermentation and bio-solids separations and their application to biochemical engineering. Computer-aided process simulation is incorporated. Prerequisites: CBEN375, CHGN428, CHGN462. Co-requisite: CBEN460, 3 hours laboratory, 1 semester hour.

CBEN469. FUEL CELL SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.
Equivalent with MEGN469,MTGN469,
Investigate fundamentals of fuel-cell operation and electrochemistry from a chemical-thermodynamics and materials-science perspective. Review types of fuel cells, fuel-processing requirements and approaches, and fuel-cell system integration. Examine current topics in fuel-cell science and technology. Fabricate and test operational fuel cells in the Colorado Fuel Cell Center. 3 hours lecture; 3 semester hours. Prerequisite: MEGN261 or CBEN357.

CBEN470. INTRODUCTION TO MICROFLUIDICS. 3.0 Semester Hrs.
This course introduces the basic principles and applications of microfluidic systems. Concepts related to microscale fluid mechanics, transport, physics, and biology are presented. To gain familiarity with small-scale systems, students are provided with the opportunity to design, fabricate, and test a simple microfluidic device. Prerequisites: CBEN307 or MEGN351. 3 hours lecture; 3 semester hours.

CBEN472. INTRODUCTION TO ENERGY TECHNOLOGIES. 3.0 Semester Hrs.
In this course the student will gain an understanding about energy technologies including how they work, how they are quantitatively evaluated, what they cost, and what is their benefit or impact on the natural environment. There will be discussions about proposed energy systems and how they might become a part of the existing infrastructure. However, to truly understand the impact of proposed energy systems, the student must also have a grasp on the infrastructure of existing energy systems. 3 lecture hours, 3 credit hours. Prerequisite: CBEN357 Chemical Engineering Thermodynamics (or equivalent).

CBEN480. NATURAL GAS HYDRATES. 3.0 Semester Hrs.
The purpose of this class is to learn about clathrate hydrates, using two of the instructor's books, (1) Clathrate Hydrates of Natural Gases, Third Edition (2008) co-authored by C.A.Koh, and (2) Hydrate Engineering, (2000). Using a basis of these books, and accompanying programs, we have abundant resources to act as professionals who are always learning. 3 hours lecture; 3 semester hours.

CBEN498. SPECIAL TOPICS. 1-6 Semester Hr.
Topical courses in chemical engineering of special interest. Prerequisite: none; 1 to 6 semester hours. Repeatable for credit under different titles.

CBEN499. INDEPENDENT STUDY. 1-6 Semester Hr.
Individual research or special problem projects. Topics, content, and credit hours to be agreed upon by student and supervising faculty member. Prerequisite: none, submission of ?Independent Study? form to CSM Registrar. 1 to 6 semester hours. Repeatable for credit.

CBEN504. ADVANCED PROCESS ENGINEERING ECONOMICS. 3.0 Semester Hrs.
Advanced engineering economic principles applied to original and alternate investments. Analysis of chemical and petroleum processes relative to marketing and return on investments. Prerequisite: none. 3 hours lecture; 3 semester hours.

CBEN505. NUMERICAL METHODS IN CHEMICAL ENGINEERING. 3.0 Semester Hrs.

Engineering applications of numerical methods. Numerical integration, solution of algebraic equations, matrix 54 Colorado School of Mines Graduate Bulletin 2011 2012 algebra, ordinary differential equations, and special emphasis on partial differential equations. Emphasis on application of numerical methods to chemical engineering problems which cannot be solved by analytical methods. Prerequisite: none. 3 hours lecture; 3 semester hours.

CBEN506. ADVANCED FUNCTIONAL POROUS MATERIALS. 3.0 Semester Hrs.

Foundation on basic chemical strategies for making nanomaterials. Integration of fundamentals and functional applications of ordered porous materials at different length scales: from micro to macroporous regime. Chemical engineering concepts in nanochemistry. Existing and emerging functional applications of these porous materials in gas separations, heterogeneous catalysis, and adsorption.

Course Learning Outcomes

CBEN507. APPLIED MATHEMATICS IN CHEMICAL ENGINEERING. 3.0 Semester Hrs.

(I, II) This course stresses the application of mathematics to problems drawn from chemical and biological engineering fundamentals such as thermodynamics, transport phenomena, and kinetics. Formulation and solution of ordinary and partial differential equations arising in chemical engineering or related processes or operations are discussed. Prerequisite: Undergraduate differential equations course; undergraduate chemical engineering courses covering reaction kinetics, and heat, mass and momentum transfer. 3 hours lecture; 3 semester hours.

Course Learning Outcomes

- n/a

CBEN508. NATURAL GAS PROCESSING. 3.0 Semester Hrs.

Application of chemical engineering principles to the processing of natural gas. Emphasis on using thermodynamics and mass transfer operations to design and analyze the process for natural gas production, processing, and use. Relevant aspects of computer aided process simulation will be applied to facilitate the learning and understand the many components associated with natural gas as an energy resource.

Course Learning Outcomes

- 1. Demonstrate a basic understanding of the industry “from wellhead to burner tip”
- 2. Develop a basic understanding of gas chemistry and resulting physical properties
- 3. Develop an understanding of the processing steps needed to abide by transportation & usage requirements and specifications
- 4. Demonstrate the ability to use simulation software for natural gas characterization, fractionation, and related operations.

CBEN509. ADVANCED CHEMICAL ENGINEERING THERMODYNAMICS. 3.0 Semester Hrs.

Extension and amplification of under graduate chemical engineering thermodynamics. Topics will include the laws of thermodynamics, thermodynamic properties of pure fluids and fluid mixtures, phase equilibria, and chemical reaction equilibria. Prerequisite: CBEN357 or equivalent. 3 hours lecture; 3 semester hours.

CBEN511. NEUROSCIENCE, MEMORY, AND LEARNING. 3.0 Semester Hrs.

Equivalent with CBEN411,

(II) This course relates the hard sciences of the brain and neuroscience to memory encoding and current learning theories. Successful students in the course should be able to read, understand, and critique current, scholarly literature on the topic of Neuroscience, Memory, and Learning. When this course is cross-listed and concurrent with CBEN411, students that enroll in CBEN511 will complete additional and/or more complex assignments. Pre-requisites: CBEN110, CBEN120, CHGN221, CHGN222, PHGN100, and PHGN200. 3 hours lecture, 3 semester hours.

Course Learning Outcomes

- Define memory types and how they relate to different types of learning and list the biochemistry of memory generation, stabilization, and maintenance.
- State how brain systems relate to episodic and semantic memory and list neuroscience bases for actions, habits, and fear
- Generate and test hypotheses to improve learning, based on biochemistry

CBEN513. SELECTED TOPICS IN CHEMICAL ENGINEERING. 1-3 Semester Hr.

Selected topics chosen from special interests of instructor and students. Course may be repeated for credit on different topics. Prerequisite: none. 1 to 3 semester hours lecture/discussion; 1 to 3 semester hours.

CBEN516. ADVANCED TRANSPORT PHENOMENA. 3.0 Semester Hrs.

Principles of momentum, heat, and mass transport with applications to chemical and biological processes. Analytical methods for solving ordinary and partial differential equations in chemical engineering with an emphasis on scaling and approximation techniques. Convective transport in the context of boundary layer theory and development of heat and mass transfer coefficients. Introduction to computational methods for solving coupled transport problems in irregular geometries.

Course Learning Outcomes

- n/a

CBEN518. REACTION KINETICS AND CATALYSIS. 3.0 Semester Hrs.

(I) This course applies the fundamentals of kinetics, transport and thermodynamics to the analysis of gas-phase and catalytic reactions. A focus is placed on a molecular description of chemical kinetics with applications to the design and analysis chemical and biological reactors, complex reaction networks, and catalysis. Prerequisite: CBEN418 or equivalent. 3 hours lecture; 3 semester hours.

Course Learning Outcomes

- n/a

CBEN519. ADVANCED TOPICS IN HETEROGENEOUS CATALYSIS. 3.0 Semester Hrs.

Heterogenous catalysts are the workhorse of the chemical industry and are responsible for many of the critical chemical transformations tied to the technological progress of our society. From enabling the development of processes to produce gasoline for transportation and fertilizers for food security, passing through the development of car catalytic converters to eliminate toxic emissions, to now being called to play a central role in many technological challenges such as transforming CO2 to useful compounds, biomass to useful fuels, water to hydrogen fuels, powering cars using fuel cells, among many others. This grad/undergrad course will take the student on a learning journey through the state-of-the-art of catalyst development. The journey will be made through the fundamental basics of both computational/theoretical and

experimental/practical aspects of catalyst development, with Special Topic sessions discussing the most up to date examples of synergistic integration of these aspects in industry and research. Not only will the student gain an understanding of what kind of critical societal problems are tried to be solved by developing new catalysts, but also will gain an understanding of how that development is taking place and what entails.
Course Learning Outcomes

- 1. Demonstrate an understanding of the crystal structures of solids and the origin of catalyst functions.
- 2. Demonstrate an understanding of adsorptions and reactions on surfaces.
- 3. Be able to use density functional theory (DFT) methods to calculate adsorption and activation energies and to estimate rate parameters from DFT-derived energies.
- 4. Be able to construct microkinetic modeling using theory-derived rate parameters and to predict rates and selectivities at catalytic conditions.
- 5. Be able to interpret experimental kinetic rate data and compare them to theory-derived values.
- 6. Demonstrate an understanding of diffusion phenomena in porous materials and its consequences on rates and selectivities.
- 7. Be able to analyze experimental and theoretical data to characterize diffusion in porous materials and to determine their textural properties.
- 8. Be able to explain different synthesis techniques to prepare catalytic materials.
- 9. Demonstrate an understanding of appropriate research tools that can be applied to characterize catalytic materials.
- 10. Demonstrate an understanding of the key physical chemistry concepts of spectroscopic methods.
- 11. Demonstrate an understanding of the applications of spectroscopic methods to answer specific research questions.

CBEN522. CHEMICAL ENGINEERING FLOW ASSURANCE. 3.0 Semester Hrs.
Chemical Engineering Flow Assurance will include the principles of the application of thermodynamics and mesoscopic and microscopic tools that can be applied to the production of oil field fluids, including mitigation strategies for solids, including gas hydrates, waxes, and asphaltenes.
Course Learning Outcomes

- 1. Demonstrate an understanding of the chemistry and physical properties of oil field production fluids and solids.
- 2. Demonstrate an understanding of the thermodynamics of oil field fluids and solids, including gas hydrates, waxes, and asphaltenes phase equilibria.
- 3. Be able to apply phase equilibrium models to predict the phase equilibria behavior of complex fluids, as well as gas solubility in water/oil systems.
- 4. Be able to apply multiphase flow transport models to predict pressure drop and slurry viscosity in oil and gas flowlines.
- 5. Demonstrate an understanding of the macroscopic, mesoscopic, and microscopic tools that can be applied to study oil field processing methods, including the control of hydrates, waxes, asphaltenes, scale.
- 6. Demonstrate an understanding of the appropriate chemical treatments and compatibility of the treatment processes for flow assurance.
- 7. Demonstrate an understanding of the key physical chemistry concepts of flow assurance.
- 8. Demonstrate an understanding of the key concepts of industrial gas transportation and storage.

CBEN524. COMPUTER-AIDED PROCESS SIMULATION. 3.0 Semester Hrs.
Advanced concepts in computer-aided process simulation are covered. Topics include optimization, heat exchanger networks, data regression analysis, and separations systems. Use of industry-standard process simulation software (Aspen Plus) is stressed. 3 hours lecture; 3 semester hours. Prerequisite: none.

CBEN530. TRANSPORT PHENOMENA. 3.0 Semester Hrs.
This course covers theory and applications of momentum, energy, and mass transfer based on microscopic control volumes. Analytical and numerical solution methods are employed in this course. Students registered for the 500-level version of this course will complete an additional project using finite element analysis software and present an oral or written report. Prerequisite: MATH225 or equivalent.
Course Learning Outcomes

- 1. Write Newton’s law of viscosity, Fourier’s law of heat conduction, and Fick’s law of diffusion. Define flux, gradient, averages, and velocity averages (i.e., bulk quantities).
- 2. Derive microscopic shell balances for the conservation of mass, momentum, energy, and chemical species, including energy sources and chemical reaction. Describe the similarities between conservation equations for momentum, energy and chemical species.
- 3. Apply the generalized equations of change for mass, energy and momentum transport in rectangular, cylindrical and spherical coordinates to describe transport problems.
- 4. Derive boundary conditions for physical problems involving transport of momentum, energy or chemical species. Distinguish between processes that occur at the interface and those that occur within the bulk fluid or material.
- 5. Choose and justify simplifying assumptions to facilitate the solution of a problem describing a physical process. State restrictions that will apply to the solution due to simplifying assumptions.
- 6. Solve limited cases of mass, momentum or energy transport, including unsteady-state and two-dimensional problems that require solutions by ordinary differential equations, separation of variables, and similarity transforms.
- 7. Describe boundary layer development in flow past a flat plate for transport of momentum, and heat or chemical species.
- 8. Define mass average and molar average velocities.
- 9. Describe moving reference frames. Interrelate various forms of Fick’s law based on mass average velocity, molar average velocity and stationary reference frames.
- 10. Describe and use analogies between momentum, heat and mass transport to obtain values for friction factors, heat transfer coefficients and mass transfer coefficients.
- 11. Define common dimensionless groups arising in transport problems (Reynolds, Prandtl, Schmidt, Sherwood, and Nusselt numbers) and relate analogous groups.
- 12. Demonstrate the ability to simulate coupled momentum, heat, and mass transfer phenomena in a technologically relevant problem using a finite element analysis solver. Further, demonstrate the ability to analyze the data and present in a written or oral report.

CBEN531. IMMUNOLOGY FOR SCIENTISTS AND ENGINEERS. 3.0 Semester Hrs.

(II) This course introduces the basic concepts of immunology and their applications in engineering and science. We will discuss the molecular, biochemical and cellular aspects of the immune system including structure and function of the innate and acquired immune systems. Building on this, we will discuss the immune response to infectious agents and the material science of introduced implants and materials such as heart valves, artificial joints, organ transplants and lenses. We will also discuss the role of the immune system in cancer, allergies, immune deficiencies, vaccination and other applications such as immunoassay and flow cytometry. Prerequisites: Biology BIOL110 or equivalent or graduate standing.

CBEN532. TRANSPORT PHENOMENA IN BIOLOGICAL SYSTEMS. 3.0 Semester Hrs.

The goal of this course is to develop and analyze models of biological transport and reaction processes. We will apply the principles of mass, momentum, and energy conservation to describe mechanisms of physiology and pathology. We will explore the applications of transport phenomena in the design of drug delivery systems, engineered tissues, and biomedical diagnostics with an emphasis on the barriers to molecular transport in cardiovascular disease and cancer.

Course Learning Outcomes

- 1. Explain the barriers of momentum and mass transfer at the organism, organ, and cellular length scales.
- 2. Explain and interpret the primary literature on biotransport phenomena.
- 3. Apply the conservation of momentum equation and constitutive relationships to biologically relevant flows on different length scales and in different media.
- 4. Apply the conservation of species equation and constitutive relationships to biologically relevant mass transfer phenomena on different length scales and in different media.
- 5. Predict the relative importance of different forces and rate processes (diffusion, convection, and reaction) using dimensional analysis.
- 6. Use the Generate Ideas Method to formulate models of physiologic and pathologic processes.
- 7. Use the Generate Ideas Method to design therapeutic and diagnostic strategies.

CBEN535. INTERDISCIPLINARY MICROELECTRONICS PROCESSING LABORATORY. 3.0 Semester Hrs.

Equivalent with MLGN535,PHGN435,PHGN535,

Application of science and engineering principles to the design, fabrication, and testing of microelectronic devices. Emphasis on specific unit operations and the interrelation among processing steps. 1 hour lecture, 4 hours lab; 3 semester hours.

CBEN550. MEMBRANE SEPARATION TECHNOLOGY. 3.0 Semester Hrs.

This course is an introduction to the fabrication, characterization, and application of synthetic membranes for gas and liquid separations. Industrial membrane processes such as reverse osmosis, filtration, pervaporation, and gas separations will be covered as well as new applications from the research literature. The course will include lecture, experimental, and computational (molecular simulation) laboratory components. Prerequisites: CBEN375, CBEN430. 3 hours lecture; 3 semester hours.

CBEN554. APPLIED BIOINFORMATICS. 3.0 Semester Hrs.

(II) In this course we will discuss the concepts and tools of bioinformatics. The molecular biology of genomics and proteomics will be presented and the techniques for collecting, storing, retrieving and processing such data will be discussed. Topics include analyzing DNA, RNA and protein sequences, gene recognition, gene expression, protein structure prediction, modeling evolution, utilizing BLAST and other online tools for the exploration of genome, proteome and other available databases. In parallel, there will be an introduction to the PERL programming language. Practical applications to biological research and disease will be presented and students given opportunities to use the tools discussed. General Biology BIOL110 or Graduate standing.

CBEN555. POLYMER AND COMPLEX FLUIDS COLLOQUIUM. 1.0 Semester Hr.

Equivalent with CHGN555,MLGN555,

The Polymer and Complex Fluids Group at the Colorado School of Mines combines expertise in the areas of flow and field based transport, intelligent design and synthesis as well as nanomaterials and nanotechnology. A wide range of research tools employed by the group includes characterization using rheology, scattering, microscopy, microfluidics and separations, synthesis of novel macromolecules as well as theory and simulation involving molecular dynamics and Monte Carlo approaches. The course will provide a mechanism for collaboration between faculty and students in this research area by providing presentations on topics including the expertise of the group and unpublished, ongoing campus research. Prerequisites: none. 1 hour lecture; 1 semester hour. Repeatable for credit to a maximum of 3 hours.

CBEN568. INTRODUCTION TO CHEMICAL ENGINEERING RESEARCH AND TEACHING. 3.0 Semester Hrs.

(I) Students will be expected to apply chemical engineering principles to critically analyze theoretical and experimental research results in the chemical engineering literature, placing it in the context of the related literature, and interact effectively with students in classroom. Skills to be developed and discussed include oral presentations, technical writing, proposal writing, principles of hypothesis driven research, critical review of the literature, research ethics, research documentation (the laboratory notebook), research funding, types of research, pedagogical methods, and assessment tools. Prerequisites: graduate student in Chemical and Biological Engineering in good standing. 3 semester hours.

Course Learning Outcomes

- Students will be able to apply chemical engineering principles to critically analyze theoretical and experimental research results in the chemical engineering literature, placing it in the context of the related literature, and interact effectively with students in classroom

CBEN569. FUEL CELL SCIENCE AND TECHNOLOGY. 3.0 Semester Hrs.

Equivalent with MEGN569,MLGN569,MTGN569,

(I) Investigate fundamentals of fuel-cell operation and electrochemistry from a chemical-thermodynamics and materials- science perspective. Review types of fuel cells, fuel-processing requirements and approaches, and fuel-cell system integration. Examine current topics in fuel-cell science and technology. Fabricate and test operational fuel cells in the Colorado Fuel Cell Center. 3 credit hours.

CBEN570. INTRODUCTION TO MICROFLUIDICS. 3.0 Semester Hrs.

This course introduces the basic principles and applications of microfluidics systems. Concepts related to microscale fluid mechanics, transport, physics, and biology are presented. To gain familiarity with small-scale systems, students are provided with the opportunity to design, fabricate, and test a simple microfluidic device. Students will critically analyze the literature in this emerging field. Prerequisites: CBEN307 or equivalent. 3 hours lecture, 3 semester hours.

CBEN580. NATURAL GAS HYDRATES. 3.0 Semester Hrs.
The purpose of this class is to learn about clathrate hydrates, using two of the instructor's books, (1) Clathrate Hydrates of Natural Gases, Third Edition (2008) co authored by C.A.Koh, and (2) Hydrate Engineering, (2000). Using a basis of these books, and accompanying programs, we have abundant resources to act as professionals who are always learning. 3 hours lecture; 3 semester hours.

CBEN584. FUNDAMENTALS OF CATALYSIS. 3.0 Semester Hrs.
The basic principles involved in the preparation, charac terization, testing and theory of heterogeneous and homo geneous catalysts are discussed. Topics include chemisorption, adsorption isotherms, diffusion, surface kinetics, promoters, poisons, catalyst theory and design, acid base catalysis and soluble transition metal complexes. Examples of important industrial applications are given. Prerequisite: none. 3 hours lecture; 3 semester hours.

CBEN598. SPECIAL TOPICS. 6.0 Semester Hrs.
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

CBEN599. INDEPENDENT STUDY. 0.5-6 Semester Hr.
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

CBEN604. TOPICAL RESEARCH SEMINARS. 1.0 Semester Hr.
Lectures, reports, and discussions on current research in chemical engineering, usually related to the student?s thesis topic. Sections are operated independently and are directed toward different research topics. Course may be repeated for credit. Prerequisite: none. 1 hour lecture-discussion; 1 semester hour. Repeatable for credit to a maximum of 3 hours.

CBEN605. COLLOQUIUM. 1.0 Semester Hr.
Students will attend a series of lectures by speakers from industry, academia, and government. Primary emphasis will be on current research in chemical engineering and related disciplines, with secondary emphasis on ethical, philosophical, and career-related issues of importance to the chemical engineering profession. Prerequisite: Graduate status.

CBEN608. ADVANCED TOPICS IN FLUID MECHANICS. 1-3 Semester Hr.
Indepth analysis of selected topics in fluid mechanics with special emphasis on chemical engineering applications. Prerequisite: CBEN508. 1 to 3 hours lecture discussion; 1 to 3 semester hours.

CBEN609. ADVANCED TOPICS IN THERMODYNAMICS. 1-3 Semester Hr.
Advanced study of thermodynamic theory and application of thermodynamic principles. Possible topics include stability, critical phenomena, chemical thermodynamics, thermodynamics of polymer solutions and thermodynamics of aqueous and ionic solutions. Prerequisite: none. 1 to 3 semester hours.

CBEN610. APPLIED STATISTICAL THERMODYNAMICS. 3.0 Semester Hrs.
Principles of relating behavior to microscopic properties. Topics include element of probability, ensemble theory, application to gases and solids, distribution theories of fluids, and transport properties. Prerequisite: none. 3 hours lecture; 3 semester hours.

CBEN617. GRADUATE TRANSPORT PHENOMENA II. 3.0 Semester Hrs.
(II) Analysis of momentum, heat, and mass transfer problems using advanced analytical and numerical methods with an emphasis on coupled transport problems and irregular geometries. Advanced analytical techniques may include regular and singular perturbation analysis, eigenvalue problems, finite Fourier transforms, and Laplace transforms. Numerical methods for solving differential equations include finite differences, finite elements, Monte Carlo methods, and computational fluid dynamics. Prerequisite: CBEN516. 3 hours lecture; 3 semester hours.
Course Learning Outcomes

- Be able to solve transport problems analytically using regular and singular perturbation analysis, eigenvalue methods, finite Fourier transforms, and Laplace transforms.
- Be able to solve transport problems numerically using finite differences, finite elements, Monte Carlo methods, and commercial software

CBEN620. ENGINEERING OF SOFT MATTER. 3.0 Semester Hrs.
(II) Soft matter is a field of inquiry involving physical systems having low moduli and which are structured on length scales ranging from about 10 nanometers up to 100 microns. This graduate level class provides a survey of relevant material systems including polymers, colloids, surfactants, liquid crystals, and biological materials. The course emphasis is on the chemical physics of soft materials and therefore requires a high level of mathematical sophistication; students should have the equivalent of one semester of graduate level applied mathematics as a prerequisite. A term paper in the form of a short publishable review of a relevant topic is a major component of the class. Prerequisites: the equivalent of one semester of graduate level applied mathematics. 3 hours lecture; 3 semester hours.
Course Learning Outcomes

- Be able to solve problems involving elastic materials including polymers, rubbers, and hydrogels through the calculation of molecular dimensions, moduli, swelling ratios, and other relevant quantities.
- Complete a publishable review article in on a topic in soft matter physics.
- Be capable of qualitatively describing different liquid crystalline phases and their technical applications. Perform calculations of free energies and other relevant thermodynamic quantities in order to predict the phase behavior of liquid crystals as a function of concentration, temperature, and pressure

CBEN624. APPLIED STATISTICAL MECHANICS. 3.0 Semester Hrs.
This course will introduce the both rigorous and approximate theories to estimate the macroscopic thermodynamic properties of systems based on laws that control the behavior of molecules. Course contents include classical dynamics and phase space, different types of ensembles, ideal and interacting gases, modern theory of liquids, ideal solids, as well as molecular simulation techniques. Prerequisite: Undergraduate-level classical thermodynamics.

Course Learning Outcomes

- be able to calculate macroscopic theromodynamic properties based on both rigorous and approxiamte microscopic models

CBEN625. MOLECULAR SIMULATION. 3.0 Semester Hrs.
Principles and practice of modern computer simulation techniques used to understand solids, liquids, and gases. The quantum mechanical and statistical foundation of thermodynamics and kinetics will be discussed. In-depth discussion of Quantum Mechanics, Molecular Dynamics, and Monte Carlo simulation techniques will follow. Modern molecular interaction models, extended ensemble approaches, hybrid multiscale techniques, and mathematical algorithms used in molecular simulations will be included. Prerequisites: CBEN509, CBEN610.

CBEN630. PROPOSAL PREPARATION. 1.0 Semester Hr.
(I) This course is designed to guide students through the steps in writing a proposal. The Proposal writing process is divided into logical steps each of which when completed will lead to the graduate student having a draft proposal that could be successfully defended. Topics include: how to conduct a literature search and maintain an up to date database of relevant sources; Writing of a literature review in the context of a proposal; how to write a testable scientific hypothesis; the format and writing of a scientific paper; how best to present data and errors; an understanding of ethics and plagiarism issues; writing of a work plan with tasks related to objectives and time budget, Gantt charts; creation of a project budget; presentation techniques and oral defense of the proposal. 1 hour lecture; 1 semester. hour. Repeatable.
Course Learning Outcomes

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CBEN690. SUPERVISED TEACHING OF CHEMICAL ENGINEERING. 3.0 Semester Hrs.
(I) Individual participation in teaching, outreach, and/or pedagogical research activities. Discussion, problem review and development, guidance of laboratory experiments, course development, supervised practice teaching. 6 to 10 hours supervised teaching; 3 semester hours. Prerequisite: Good academic standing, CBEN 507, CBEN 509, CBEN 516, CBEN 518.
Course Learning Outcomes

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CBEN698. SPECIAL TOPICS IN CHEMICAL ENGINEERING. 3.0 Semester Hrs.
Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles. Prerequisite: none.

CBEN699. INDEPENDENT STUDY. 0.5-6 Semester Hr.
(I, II, S) Individual research or special problem projects supervised by a faculty member, also, when a student and instructor agree on a subject matter, content, and credit hours. Prerequisite: ?Independent Study? form must be completed and submitted to the Registrar. Variable credit: 0.5 to 6 credit hours. Repeatable for credit under different topics/ experience and maximums vary by department. Contact the Department for credit limits toward the degree.

CBEN707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr.
(I, II, S) Research credit hours required for completion of a Masters-level thesis or Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit.