BMEG 250: Cellular physiology & biophysics

This course expands understanding about cellular structure and investigates fundamental mechanisms of membrane transport, signal transduction, muscle mechanochemistry and neurotransmission. Structure and hierarchical organization up to the level of tissues are also studied using light and electron microscopy.

LEARNING OBJECTIVES

After the course, students will be able to:

- Understand cellular structure and intracellular organization of organelles
- Understand fundamentals of light and electron microscopy
- Operate light and electron microscopes for investigating cells and tissues
- Relate biophysical chemistry to cellular structure, as well as cellular interactions within tissues
- Understand biochemical properties of membrane lipids and investigate the structure of cellular membranes
- Understand membrane potentials and their impact on transport into and outside the cell
- Differentiate between the physiology of passive diffusion, facilitated diffusion, co-transport and counter-transport
- Relate membrane excitability to the physiology and function of ionotropic and metabotropic channels
- Understand the biology of gap junctions
- Understand the role of ion channels in pharmacobiology
- Understand signal transduction and how intracellular signaling cascades are initiated in response to extracellular stimuli
- Understand the chemistry and physiology of synaptic transmission
- Understand mechanochemistry and relate it to excitation and contraction of muscle tissue
- Understand and exploit molecular machines for cellular bioengineering

COURSE SCHEDULE

Lectures - 3 sessions of 1 hour each per week (36 total; 3 credits).
Labs - 1 session of 3 hours every three weeks (4 total; 1 credit)

Week	Description
1	Cellular structure and organelles, compartmentalization of cellular physiological functions
2	Investigating cell and tissue structure using light & electron microscopy
3	Biophysical chemistry of physiological solutions and metabolism, review of biological thermodynamics
4	Biochemical properties of membrane lipids, structure of cellular membranes, Singer-Nicholson fluid mosaic model
5	Membrane potentials, Gibbs-Donnan equilibrium potentials, Fickian diffusion
6	Facilitated transport across membranes, co-transport, counter-transport, ion pumps
7	Osmosis & regulation of cellular volume, regulation of intracellular pH
8	Membrane excitability, structure & mechanism of voltage-gated ion channels

9 Gap junctions, ligand-gated ion channels

10 Interaction of ion channels with cytoskeleton, targeting ion channels for drug development

11 Intracellular signaling cascades, cellular responses to external stimuli, neurochemistry, synaptic transmission

12	Smooth muscle excitability, mechanochemistry, contraction of muscles
13	Protein-protein interactions and molecular machines, application of molecular machines in bioengineering

STUDENT EVALUATION

Evaluation 1	Date	X %
Laboratory reports	4 reports per term (2.5% each)	10%
Evaluation 2	Date	X %
Homework assignments	5 assignments per term (2% each)	10%
Evaluation 3	Date	X%
Midterms 30%	Two midterms (15% each)	
Evaluation 3	Date	%
Final Exam	Cumulative	50%

The course covers fundamental concepts involved in the sizing and operation of batch, semi-batch, continuous, plug flow and packed bed reactors. An analytical approach based on first principles is emphasized. The course is divided into 4 modules. The first module comprises introductory principles such as mole balances, stoichiometry, rate laws, thermochemistry, chemical equilibrium and derivation of rate laws. The second module introduces the different types of ideal reactors and instructs students about sizing reactors using concentrations and conversions. The third module introduces students to enzyme catalysis and elementary bioprocess engineering. The fourth module covers non-ideal reactor design and chiefly focuses on steady-state non-isothermal reactors and residence time distributions. Topics such as heat and mass transfer are also reviewed.

LEARNING OBJECTIVES

After the course, students will be able to:

- Explain the operating principles of different reactor types such as continuous stirred-tank, plug-flow and batch reactors
- Derive the mathematical equations that govern the operation of different reactor types
- Operate PFRs for gas-phase reactions
- Account for pressure drops in packed-bed reactors
- Non-dimensionalize reactor design problems through use of conversion and dimensionless numbers such as the Damköhler number
- Use numerical methods to solve system of ODEs that describe reactor performance
- Analyze reaction data to estimate rate parameters
- Derive rate expressions for enzymes and use this information to size bioprocesses
- Model microbial growth in bioreactors
- Quantify the contribution of mass transport in reacting systems
- Account for molecular and macroscopic phenomena in the design a packed-bed reactor
- Perform energy balances on reacting systems to relate performance of the reactor to its operating temperature
- Diagnose and model non-ideal mixing in a reactor

COURSE SCHEDULE

Lectures - 2 sessions of 80 minutes each week
Tutorials - 1 session of 50 minutes each week

Week	Description
1	History of chemical reaction engineering: The Haber-Bosch process Review of physical chemistry
2	Definition of reaction rate, rate constant, order Reaction stoichiometry
3	Mole balances Continuous-stirred tank reactors Plug-flow reactors
4	Conversion Reactors-in-series Levenspiel plots

5 Gas-phase reactions in plug-flow reactors
Pressure drops in packed-bed reactors
Selectivity & yield

6 Analysis of rate data
Numerical methods for solving reaction engineering problems

7 Fick's law of diffusion
Convection
Flux balances

8 Mass transport within reacting systems
Design of a packed-bed reactor

9 Enzyme catalysis
Michaelis-Menten equation
Enzyme inhibition

10 Microbial growth
Bioprocess design

11 Energy balances
Non-isothermal reactors

12 Heat exchangers and reactors
Residence time distributions

13 Models for non-ideal mixing
Course recap