College of Engineering
Departments of Bioengineering and Mechanical Engineering
Expanded Course Description

Course: Bio Eng C215/Mec Eng C216
Title: MOLECULAR BIOMECHANICS AND MECHANOBIOLOGY OF THE CELL
Units: 4
Course Format: 3 hours of lecture and 1 hour discussion
Instructor: Mohammad R. K. Mofrad
Prerequisites: Math 54; Physics 7A; BioE102 or MEC85 or instructor's consent
Grading: Letter
Estimated Number of student hours: 12

General Catalog Course Description:
This course applies methods of statistical and continuum mechanics to subcellular biomechanical phenomena ranging from nanoscale (molecular) to microscale (whole cell and cell population) biological processes at the interface of mechanics, biology and chemistry.

Course Objectives:
This course, which is open to graduate students in diverse disciplines ranging from engineering to biology to chemistry and physics, is aimed at exposing students to subcellular biomechanical phenomena spanning scales from molecules to the whole cell.

Desired Course Outcome:
The students will develop tools and skills to (1) understand and analyze subcelluar biomechanics and transport phenomena, and (2) ultimately apply these skills to novel biological and biomedical applications.

Grading:	Homework	15%
	Class presentation and active participation	10%
	2 Mid-term exams	50%
	Final term project, paper and presentation	25%

Problems will be assigned each week to be handed in and graded. There will be two midterm exams and a final project term paper and presentation due at the end of the term.

Term Paper:
A project and term paper will be assigned that will require the students to delve more deeply into one of the topics of the course.

Weekly discussions will cover examples related to the topics covered in the lectures, and will also provide directions for the term project.

Weekly problem sets
Drill on lecture material to reinforce engineering principles and prepare student for exams.

Textbooks:
- Mofrad MRK and Kamm RD Eds. **Cellular Mechanotransduction: Diverse Perspectives from Molecules to Tissues**, Cambridge University Press, 2014.

- Mofrad MRK and Kamm RD Eds. **Cytoskeletal Mechanics: Models and Measurements in Cell Mechanics**, Cambridge University Press, 2011.

In addition, notes, journal articles, and specific chapters of the following recommended books will be assigned for reading.

- J. Howard, **Mechanics of Motor Proteins and the Cytoskeleton**, 2001
- D. Boal, **Mechanics of the Cell**, Cambridge University Press, 2001.
- K. Dill and S. Bromberg, **Molecular Driving Forces**, 2003.

Room Share & Graduate Content: BioEc112/MEc115 & BioEc215/MEc216 will share the same lectures. However for the graduate version, students will be required to prepare and present a final project that must include a mock NSF-type proposal for research, related to the topics discussed in the course. Undergraduates will prepare a final project that does not require a research proposal but includes an extensive literature review/critique related to the topics covered in the course.

Syllabus

WEEK	LECTURE TOPIC
1	**Introduction to Biomechanics: From Biomolecules to the Cell Mechanics** Course introduction, overview and logistics.
	❑ **BIOMOLECULAR MECHANICS**
2	**Length, Time, Energy, and Forces in Biology** Molecules of interest: DNA, proteins, actin, peptides, lipids Molecular forces: charges, dipole, Van der Waals, hydrogen bonding kT as ruler of molecular forces
3	**Thermal Forces and Brownian Motion** Molecular life and motion at low Re Langevin and Brownian Dynamics
.4	**Thermodynamics and Elementary Statistical Mechanics** Review of classical thermodynamics: entropy, equilibrium, open systems, ensembles, Boltzmann distribution, entropic forces
5	**Thermodynamics and Elementary Statistical Mechanics (continued)** Ensembles, canonical ensemble, microcanonical ensemble, grand canonical ensemble, partition function, Boltzmann distribution, free energies, entropic forces
6	**Ideal Polymer Chains and Entropic Elasticity** Statistics of random walks Gaussian polymer Freely jointed chain (FJC) Origins of elastic forces The worm-like chain model

Persistence length as a measure of rigidity

7 **Molecular Mechanics and Dynamics: Fundamentals**
Macromolecular structure and modeling
Force Fields
Normal modes
Bond length, bond angle, and torsional potentials, Van der waals potential, Coulomb potential

8 **Molecular Mechanics and Dynamics: Applications**
Molecular rigidity
Steered molecular dynamics
Mechanical unfolding pathways and dynamics

- **CELL MECHANICS**

9 **Structure of the Cell**
Cellular anatomy, cytoskeleton
Membrane
Types of attachment to neighboring cells or the ECM, receptors
Different cell types

10 **Biomembranes**
Stiffness & role of transmembrane proteins
Equations for a 2-D elastic plate
Membrane cortex
Vesicles: model systems.

11 **The Cytoskeleton**
Fiber microstructure
Actin and microtubule dynamics, methods of visualizing actin diffusion and polymerization

12 **Quantitative Aspects of Cell Mechanics**
Review of continuum mechanics, theories of elasticity, viscoelasticity, and poroelasticity
Rheology of the cytoskeleton
Active and passive measures of deformation
Storage and loss moduli and their measurements
Models of the cytoskeleton: continuum, microstructural – tensegrity, cellular solids, polymer solution.
Experimental measurements of mechanical behavior
Cell peeking and poking

13 **The Nucleus**
The structure and mechanics of the nucleus
Modeling and experimental approaches to understand the nucleus
Mechanics and transport in the nucleus

14 **Mechanotransduction**
Intracellular signaling relating to physical force
Molecular mechanisms of force transduction

		Force estimates and distribution within the cell
15		**Term project presentations**