University Of California, Berkeley
Department of Mechanical Engineering

ME C115/Bio E C112: Molecular Cell Biomechanics (4 units)

Undergraduate Elective

Syllabus

CATALOG 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 PREREQUISITES

Math 54; Physics 7A; BioE102 or MEC85 or instructor's consent

TEXTBOOK(S) AND/OR OTHER REQUIRED MATERIAL

Notes and journal articles will be handed out by the instructor. The following texts will be recommended and placed on short-term reservation in the library:

- D. Boal, **Mechanics of the Cell**, Cambridge University Press, 2001.
- K. Dill and S. Bromberg, **Molecular Driving Forces**, 2003.
- J. Howard, **Mechanics of Motor Proteins and the Cytoskeleton**, 2001
- Mofrad MRK and Kamm RD. **Cytoskeletal Mechanics: Models and Measurements**, Cambridge University Press, 2006.

COURSE OBJECTIVES

This course, which is open to senior undergraduate 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 OUTCOMES

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.

TOPICS COVERED

See weekly topics.

CLASS/LABORATORY SCHEDULE

3 hours of lecture and 3 hours of laboratory per week

RELATIONSHIP OF THE COURSE TO ABET PROGRAM OUTCOMES

(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(e) an ability to identify, formulate, and solve engineering problems
(g) an ability to communicate effectively

ASSESSMENT OF STUDENT PROGRESS TOWARD COURSE OBJECTIVES

Homeworks	20%
2 Mid-term exams	50%
Final term project, paper and presentation	30%

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. The project can be devoted to a design or analysis effort related to molecular or cell biomechanics problems abundant in biology and medicine. The students are welcome to work individually or in groups of 2 for the project.

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

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

SAMPLE OF WEEKLY AGENDA

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**

PERSON(S) WHO PREPARED THIS DESCRIPTION
Professor Mohammad Mofrad
2011

ABBREVIATED TRANSCRIPT TITLE (19 SPACES MAXIMUM): MOLEC CELL BIOMECS
TIE CODE: LECS
GRADING: Letter
SEMESTER OFFERED: Fall and/or Spring
COURSES THAT WILL RESTRICT CREDIT: None
INSTRUCTORS: Mofrad
DURATION OF COURSE: 14 Weeks
EST. TOTAL NUMBER OF REQUIRED HRS OF STUDENT WORK PER WEEK: 12
IS COURSE REPEATABLE FOR CREDIT? No
CROSSLIST: BioEngineering C112