Updated 9/3/2019

Chemistry 01:160:437, Chemistry 16:160:537
Biophysical Chemistry I, Fall 2019

This interdisciplinary course explores the physical interactions and chemical reactions behind biological phenomena. Topics will include Brownian motion; reaction kinetics; mechanical, structural, and thermal properties of proteins, nucleic acids, and membranes; intermolecular and surface forces; introductory electrophysiology; low Reynold number flow; and recent technical advances in biophysical chemistry. The goal of the class is to teach students to think quantitatively about biological measurements and to understand how quantitative biophysical measurements are made.

Primarily for advanced undergraduate students and graduate students with an interest in interdisciplinary research.

Prerequisites: physical chemistry 327 or physical chemistry 341, or on permission of the instructor.

Hours and Location: Tuesday and Thursday, 3:20 pm - 4:40 pm; at CCB-1209, 123 Bevier Road, Piscataway, NJ 08854

First class meets on Tuesday, Sept. 3

Instructor:

Zheng Shi, Assistant Professor of Chemistry and Chemical Biology, Rutgers University.

Email: zheng.shi@rutgers.edu; office: CCB-4220; phone: (848) 445-3246.

Office hours: CCB-4220, Thursday 4:40 pm to 6 pm, or by appointment.

Textbooks:

Phillips, Kondev, Theriot, Garcia. *Physical Biology of the Cell*, Garland Science, 2nd Edition, 2012. (Required)

Israelachvili, *Intermolecular and Surface Forces*, Academic Press, 3rd Edition, 2011. (Optional)

Berg, *Random Walks in Biology: New and Expanded Edition*, Princeton Press, 1993. (Optional)

Homework (30%): 10 weekly problem sets will emphasize calculations and extensions of the ideas developed in class. Problem set grades will be docked 15% per day late.

Midterm (20%): an in-class midterm will test understanding of the key ideas in the course.

Final Project (40%): The final project will focus on how a physical approach can be applied in a problem in molecular or cellular biology. Students will either extensively/critically review a topic in biophysical chemistry, or propose a new experiment, or develop a new physical model for a known phenomenon.

Each student will give a ~15 min presentation to the class, which is followed by a ~5 min in-class discussion on the presented topic. The presenter is expected to address questions that arose during

the discussion. Each student will then write a ~3 page paper on the chosen topic. The paper is due one week after the last session.

Participation (10%): Students are encouraged to participate in discussions during class and during the final project presentations.

Students enrolled in the course will be subject to the Rutgers University Academic Integrity Policy (http://academicintegrity.rutgers.edu/academic-integrity-at-rutgers/).

Schedule: (subject to revision)

Session 1 (Sept. 3)

Introduction: Role of physics and chemistry in biology. Examples of biological problems amenable to physical solutions. Characteristic sizes, shapes, times, and energies in biology. *Decide on class logistics.*

Reading: PBOC Ch. 1; *Ch. 2 – 4 (optional);* Ben Franklin.

HW 1 assigned.

Session 2 (Sept. 5)

Thermal fluctuations. Energy budget of a cell. Chemical equilibrium. First order and pseudo-first order reaction kinetics. Higher order reactions. Taylor expansion.

Reading: PBOC Ch. 3.4; Ch. 5.1 – 5.2.3; Ch. 15.1 – 15.2; Intro. M. Meister paper.

Session 3 (Sept. 10)

Mechanical equilibrium. Hooke's law; Young's modulus. Optical trap. Entropy; Free energy; Hydrophobicity. Boltzmann distribution.

Reading: PBOC p. 154; Ch. 5.2.4 – 5.6; Ch. 6.1; Ashkin (2018 Nobel lecture).

HW 1 due, HW 2 assigned.

Session 4 (Sept .12)

Ideal gas; dilute solution; Osmotic pressure. Law of mass action. Ligand-receptor binding. Two state system; Ion Channels; Cooperative binding.

Reading: PBOC Ch. 6.2 - 6.5; Ch. 7.

Session 5 (Sept. 17)

Random walks; Brownian motion. Statistics of Brownian motion. Central limit theorem.

Reading: PBOC Ch. 13.1 – 13.2; Howard appendix (optional).

HW 2 due, HW 3 assigned.

Session 6 (Sept. 19)

Diffusion equation and its solutions. Fick's Law. Stokes Einstein Relation. Diffusion-limited reaction rates. Equipartition Theorem.

Reading: PBOC Ch. 13.3 – 13.4.

Session 7 (Sept. 24)

Applications of Brownian motion: Chemotaxis in E. coli; limits on size of organisms; tumor growth; diffusion of photons in tissue; diffusion and drag in porous medium.

Reading: Berg (optional); PBOC p.159 – 161;

HW 3 due, HW 4 assigned.

Session 8 (Sep. 26)

Intermolecular forces: Covalent/Coulomb, Van der Waals, Hydrogen bonds.

Reading: Israelachvili Ch. 1 - 4.

Session 9 (Oct .1)

Entropic forces. Depletion forces. Entropy-induced order. Crowding.

Reading: PBOC Ch. 14.

HW 4 due, HW 5 assigned.

Session 10 (Oct. 3)

Polymers: persistence length, DNA and RNA stretching.

Reading: PBOC Ch. 8.

Session 11 (Oct. 8)

Continuum mechanics of rods, cytoskeleton. Bending, twisting, and buckling.

Reading: PBOC Ch. 10.

HW 5 due, HW 6 assigned.

Session 12 (Oct. 10)

Thermodynamics of self-assembly. Lipids. Micelles. Critical micelle concentration.

Reading: Israelachvili Ch. 19

Session 13 (Oct. 15)

Bilayers. Vesicles. Membranes at finite temperature. Fluctuation of lipid bilayers. Continuum mechanics of membranes.

Reading: Israelachvili Ch. 20

HW 6 due, HW 7 assigned.

Session 14 (Oct. 17)

Membrane stretching and bending. Membrane tubes. Fluid-Mosaic model. Diffusion and drag in 2D.

Reading: PBOC Ch. 11. Literature: Singer, Engelman, Jocobson, Shi and Cohen…

Session 15 (Oct. 22)

Fluorescence. Fluorescent microscopy. Fluorescent proteins.

Reading: Literature: Tsien (2008 Noble lecture), Nikon Microscopy U.

HW 7 due, HW 8 assigned.

Session 16 (Oct. 24)

Interactions between protein and membranes in cells. Endocytosis, exocytosis, actin cytoskeleton, transmembrane proteins.

Reading: Literature: Südhof (2013 Nobel lecture), Rothman (2013 Nobel lecture), DeCamilli, Kirchhausen, Shi and Baumgart...

Session 17 (Oct. 29)

Midterm

Session 18 (Oct. 31)

Membrane potential and Nernst Equation.

Reading: PBOC Ch. 17.1 – 17.2

Midterm feedback

Session 19 (Nov. 5)

Introduction to electrophysiology. Ion channels and pumps. Electrogenetic transporters.

Reading: PBOC Ch. 17.3 – 17.4

HW 8 due

Session 20 (Nov. 7)

Electrostatics in solution: Poisson-Boltzmann, Debye-Hückel theory. Coagulation, flocculation.

Reading: PBOC Ch. 9.

HW 9 assigned.

Session 21 (Nov. 12)

Fluid dynamics: Poiseuille flow, Reynolds number, surface tension. Swimming vs. waiting. Blood flow.

Reading: PBOC Ch. 12.

Session 22 (Nov. 14)

Navier-Stokes. Fluctuation spectrum. Brinkman. Flow in porous medium.

Reading: Literature: Brochard, Bussel, Shi and Cohen…

HW 9 due, HW 10 assigned.

Session 23 (Nov. 19)

Recent advances in biophysical chemistry. Super-resolution. Molecular sensors. Optogenetics. Magnetogenetics?

Reading: Zhuang (iBiology), Betzig, Hell (2014 Nobel lecture); Cohen, Looger; Boyden, Dessertoth…

Session 24 (Nov. 21)

Future challenges and opportunities in biophysical chemistry.

Reading: mechanosensation, protein folding, tool development…

HW 10 due

Sessions 25 (Nov. 26) (**before Thanksgiving Recess)*

In-class reading and discussion. Decide on the topics of final project.

Sessions 26 (Dec. 3)

Presentations and discussions of final projects.

Sessions 27 (Dec. 5)

Presentations and discussions of final projects.

Sessions 28 (Dec. 10)

Presentations and discussions of final projects.

Serving students with Disabilities

Students who need accommodations in this class can do so through the Rutgers Disabilities Service Office.