Chemistry 01:160:541
Special Topics Physical Chemistry, Fall 2021

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, membranes, and biomolecular assemblies. We will also discuss recent technical advances in biophysics. 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 first year 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, 5:00 pm - 6:20 pm; at CCB-3217, 123 Bevier Road, Piscataway, NJ 08854-8008

First class meets on Thursday, Sept. 2

Instructor:

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

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Website: https://sites.rutgers.edu/shi-lab/

Office hours: Thursdays after class.

Textbooks:

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

Vogel, *Comparative Biomechanics (Life's Physical World)*, 2nd Edition, 2013. (Optional)

Nelson, *Biological Physics Student Edition: Energy, Information, Life*, 2020. (Optional)

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

Homework (30%: 10 *15 pt): 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%: 100 pt): an in-class midterm will test understanding of the key ideas in the course.

Final Project (40%: 200 pt): 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 related to this course, or propose a new experiment, or develop a new physical model for a known phenomenon. Each student will give a ~20 min presentation to the class,

followed by a 5~10 min in-class discussion. 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%: 50 pt): 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: (updated on Sept. 23)

Session 1 (Sept. 2)

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. 7)

Thermal fluctuations. Energy budget of a cell. Chemical equilibrium. First order reaction kinetics

Reading: PBOC Ch. 3.4; Ch. 5.1 – 5.2.3; Ch. 15.1 – 15.2; Magnetogenetics?

Session 3 (Sept. 9)

Pseudo-first order reaction kinetics, binding constant. Higher order reactions. Mechanical equilibrium. Hooke's law; Young's modulus. Optical trap.

Reading: PBOC p. 154; Ch. 5.2 – 5.4; Ashkin and Chu (2018 Nobel lecture).

HW 1 due, HW 2 assigned.

Session 4 (Sept .14)

Entropy; Free energy; Hydrophobicity. Boltzmann distribution.

Law of mass action. Ligand-receptor binding. Two state system; Ion Channels; Cooperative binding.

Reading: PBOC Ch. 5.5, Ch. 6.1.

Session 5 (Sept. 16)

Ideal gas; dilute solution; Osmotic pressure.

Reading: PBOC 6.2-6.4

(optional) Ch. 14. Entropic forces. Depletion forces. Entropy-induced order. Crowding.

HW 2 due, HW 3 assigned.

Session 6 (Sept. 21) (Zoom)

https://rutgers.zoom.us/j/95406565336?pwd=NzNEdmxNZis2a05ZQlRLU1dmNjVzZz09

Guest lecture: Mikolai Fajer
Computation chemistry in drug discovery

Session 7 (Sept. 23)

leftover from Session 5

Intro. to Matlab and image processing

Session 8 (Sep. 28)

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

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

Reading: PBOC Ch. 13.1 – 13.4

HW 3 due, HW 4 assigned.

Session 9 (Sep. 30)

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. Langevin, FCS and DLS

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

Session 10 (Oct. 5)

Biopolymers, persistence length.

Reading: PBOC Ch. 8.

Session 11 (Oct. 7)

DNA and RNA stretching. Single molecules.

Reading: PBOC Ch. 8.

HW 4 due, HW 5 assigned.

Session 12 (Oct. 12)

Continuum mechanics of rods, cytoskeleton.

Reading: PBOC Ch. 10.

Session 13 (Oct. 14)

Bending, twisting, and buckling of cytoskeleton.

Reading: PBOC Ch. 10.

HW 5 due, HW 6 assigned.

Session 14 (Oct. 19)

Thermodynamics of self-assembly. Chemistry of lipids. Micelles. Critical micelle concentration.

Reading: Israelachvili Ch. 19, 20

Session 15 (Oct. 21)

Bilayers. Vesicles. Membranes at finite temperature. Fluctuation of lipid bilayers. Membrane stretching and bending. Membrane tubes. Cell membranes.

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

HW 6 due, HW 7 assigned.

Session 16 (Oct. 26)

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

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

Session 17 (Oct. 28)

Membraneless organelles, viscosity and surface tension of biomolecular condensates, Liquid-liquid phase separation in biology

HW 7 due, HW 8 assigned.

Session 18 (Nov. 2)

Midterm

Session 19 (Nov. 4)

Fluorescence. Fluorescent microscopy. Fluorescent proteins.

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

Midterm feedback

Session 20 (Nov. 9)

Membrane potential and Nernst Equation.

Reading: PBOC Ch. 17.1 – 17.2

Session 21 (Nov. 11)

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

Reading: PBOC Ch. 17.3 – 17.4

HW 8 due, HW 9 assigned.

Session 22 (Nov. 16)

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

Reading: PBOC Ch. 12.

Session 23 (Nov. 18)

Navier-Stokes. Fluctuation spectrum. Brinkman. Flow in porous medium. Diffusion and drag in 2D.

Reading: Literature: Brochard, Bussel, Shi and Cohen

HW 9 due, HW 10 assigned.

Session 24 (Nov. 23)

Recent advances in biophysical tools. Super-resolution. Molecular sensors. Optogenetics. CRISPR-Cas9. mRNA therapeutics.

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

Sessions 25 (Nov. 30)

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

HW 10 due

Sessions 26 (Dec. 2)

Presentations and discussions of final projects.

Sessions 27 (Dec. 7)

Presentations and discussions of final projects.

Sessions 28 (Dec. 9)

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.