PHY372. Physical Concepts and Modeling in Cell Biology

Spring 2007

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Time and Location: MWF 09:10-10:00 Lewis Lab 512

Course website http://athena.physics.lehigh.edu/

Aims

To introduce to students in the physical and biological sciences and in engineering topics in cell biology involving interdisciplinary methods for quantitative modeling and analysis.

Description

Modern biological research is becoming more quantitative. Advances in experimental methods allow us to study with extreme detail processes within the basic unit of life, the cell, all the way down to the level of molecules. We can watch DNA, proteins and lipids assemble into elaborate dynamic structures such as chromosomes, organelles, membranes, and filaments within living cells. A major challenge in modern science is to (1) find ways to extract quantitative information from such experiments, and (2) use this information to formulate predictive models which capture the essence of the underlying mechanisms. The course is an introduction to recent research in this area.

Using a few selected biological examples, we will get a feeling of the physical environment and of the amazing complexity within the cell. We will discuss how biomolecular assemblies have evolved to perform specific tasks in a place dominated by noise, variability, and thermal fluctuations. Dealing quantitatively with complex biological systems often requires the use of mathematical and computational modeling. We will discover how essential such tools are, but also some common pitfalls.

Textbooks

For the part of the course dealing with the “physical principles in the cell” we will refer to chapters in the following textbooks: (1) “Mechanics of Motor Proteins and the Cytoskeleton,”
by J. Howard, (2) “Biological Physics,” by P. Nelson, (3) “Random Walks in Biology,” by H. C. Berg, and (4) the draft version of the book “Physical Biology of the Cell,” currently being written by R. Phillips, J. Kondev, and J. Theriot. We will then refer to research articles for examples of modeling of cell biological processes.

The above textbooks are recommended but not required.

**Grading**

Students in this course may have different backgrounds and different levels of exposure to mathematics, physics, and biology. So instead of a final exam the course grade will be largely based on a course project. Each student will work on a topic which is close to his/her background and interests. The topic will be decided after discussion with the instructor. The project will consist of a written report and a short oral presentation. The best reports will be permanently posted on the web page of the course.

The final grade will be based on:

1. **Course project** (50%).
2. **Homework** (20%). Assignments must be submitted on the assigned due date. Prior permission from the instructor is required for late submissions.
3. **Active participation** in class (30%).

**Prerequisites**

Calculus, Physics 11, 13/21.

**Notes**

1. Cell biology is a vast field. The focus this semester will be on topics related to the dynamics of the cytoskeleton. We will only briefly discuss topics on membrane dynamics and information processing by genomes.
2. You can get an idea of the molecular processes in the cell in this fascinating movie: [http://multimedia.mcb.harvard.edu](http://multimedia.mcb.harvard.edu).

Accommodations for Students with Disabilities: If you have a disability for which you are or may be requesting accommodations, please contact both your instructor and the Office of Academic Support Services, University Center 212 (610-758-4152) as early as possible in the semester. You must have documentation from the Academic Support Services office before accommodations can be granted.
Bibliography


Tentative Course Outline

A. A Quantitative Overview of the Cell.

- **Week 1.** Introduction. Spatial, temporal, and energy scales in the cell. Molecular and thermal diffusion. Inertia. Concentrations.
- **Week 2.** Basic mechanics of structures in the cell. Chemical Forces.
- **Week 3.** Examples of cell biological processes. Cartoons, scaling arguments, and computer models.

B. Biophysics of Diffusion and Binding.

- **Week 4.** Statistical mechanics of binding. Diffusion.
- **Week 5.** Diffusion-controlled association and the importance of dimensionality.
- **Week 6.** How a bacterium senses a nutrient gradient. How a dividing bacterium determines its center.

C. Dynamics of Macromolecular Assemblies.

- **Week 7.** The cytoskeleton and molecular motors. ATP hydrolysis as a source of free energy and the principle of detailed balance.
- **Week 8.** More on diffusion and binding: cargo transport along neurons.

D. Extracting Quantitative Information from Experiment.

- **Week 12.** Quantitative fluorescence microscopy. FRAP.
- **Week 13.** Fluorescence correlation spectroscopy. Tracking.
- **Week 14.** Simulated data. Software for analysis and modeling.