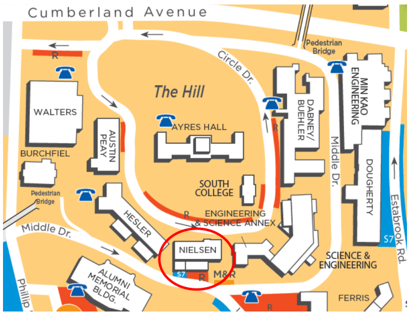
Physics 642/490: Biophysics, Fall 2018

University of Tennessee, Knoxville

Time: MWF, 11:15 AM–12:05 PM
Place: Nielsen Physics Building - 512



Instructor: Maxim O. Lavrentovich

Office location: Nielsen 406A
Office hours: WF, 2:00-3:00 PM
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Course description: Graduate-level course on various topics at the interface between biology and statistical physics. Introduction to physical biology. Physics of macromolecules (DNA, RNA). Diffusion and absorption of small molecules. Molecular motor kinetics. Transcription networks. Pattern formation. Dynamics and evolution of populations.
Credit Hours: 3
Course Section: 001
Prerequisites: Some familiarity with statistical mechanics

Overall Goals and Learning Objectives

Biology has increasingly benefited from quantitative approaches. This course is an introduction to such approaches, with a focus on methods from statistical physics. We will build up a physical understanding of biology ranging from the 0.1-10 nm molecular scale, the 1-100 μm scale of the single cell, and all the way up to the 1 m-1 km scale of populations of living organisms. We will begin by treating important biological molecules (including proteins, DNA, and RNA) using polymer physics concepts. Then, we will build an understanding of how many of these molecules interact at a single-cell scale (in polymer mixtures, regulatory networks, molecular motor motion, etc.). We will then consider multiple cells and construct mathematical descriptions of cell population dynamics (in growing, invading populations, pattern-forming tissues, etc.). The course also serves as a continuation of a typical undergraduate thermal physics class, and will introduce more advanced physical and mathematical topics such as the random walk, the kinetic Ising model, the Fokker-Planck equation, the birth/death process, pattern-forming partial differential equations, etc. We will also cover critical phenomena and phase transitions. By the end of the course you will be able to:

- absorb foundational biological concepts, including the central dogma, the cell cycle, principles of transcription regulation and gene networks, and the basics of evolution

- analyze many variants of the random walk, including finding first-passage probabilities, walker distributions in different dimensions, the effects of absorbing boundaries, etc.
- know how to describe polymers via the freely-jointed chain, worm-like chain, and Kratky-Porod models, developing notions of the persistence and Kuhn lengths, gyration radius, force-extension relationships
- use thermodynamics and notions from the theory of phase transitions and critical phenomena to describe polymer conformations, solvation, and cooperative binding
- write down probability evolution equations to describe a wide range of processes including chemical reactions, cell birth and death, and molecular motor motion
- appreciate the importance of number fluctuations in protein dynamics and cell population evolution
- have a basic understanding of network dynamics and gene expression regulation
- build mathematical models of spatio-temporal dynamics of biological pattern formation and spatial population genetics
- gain a better appreciation for the broad applicability of thermodynamics and statistical models
- get a sense of the computational and mathematical tools used in cutting-edge theoretical biophysics

How to Be Successful in This Course

Biophysics is a relatively new scientific discipline and many of the foundational concepts are still under development. This course is intended to bring you up to speed with the state of the art in this field. Therefore, there are no good centralized sources of information on many of the topics, and it is important to learn how to develop your own understanding via *multiple* sources, including textbooks, scientific articles, online lecture notes, etc. The class lectures will also present topics in a unique way, so it will be important to *regularly attend class and take your own notes*. Recording your own notes will help reinforce the concepts in your memory. If you have to miss a lecture, please contact the instructor for information about what was covered. Supplemental reading material will also be provided during the course from time to time.

The majority of the learning will take place during the *completion of the homework assignments*. You should start on the assignments as early as possible, and not hesitate to ask questions about the problems if you are stuck. The homework should take up the majority of the work for this course outside of the classroom. You are expected to work with your fellow classmates on the problems, but any work you turn in should of course be your own.

Finally, please be sure to contact the instructor immediately about any concerns about credits earned on exams, homework, and the participation-related grade.

Materials and Textbooks

There are no required textbooks for the course, as we will cover a wide range of topics which no single book covers. However, a large portion of the material covered by the class is treated in three optional textbooks, and especially in *Physical Biology of the Cell* (PBC) by R. Phillips et al.:

- Optional textbook covering many of the biological concepts in the course: *Physical Biology of the Cell* (PBC) by R. Phillips, J. Kondev, J. Theriot, and H. G. Garcia, Garland Science; 2nd Ed. ISBN: 978-0815344506
- Optional textbook covering the most basic statistical physics concepts encountered in the course and serves as a good review for undergraduate-level statistical mechanics: *Molecular Driving Forces* (MDF) by Ken A. Dill and Sarina Bromberg, Garland Science; 2nd Ed. ISBN: 978-0815344308
- Optional textbook covering many of the mathematical and biological concepts, such as stochastic processes, probability theory, etc., encountered in the course: *Physical Models of Living Systems* (PMLS) by Philip Nelson, W. H. Freeman and Company; ISBN: 978-1464140297
- Additional resources
  - For more biological details, the canonical textbook is: *Molecular Biology of the Cell* by B. Alberts et al., Garland Science; 3rd Ed. ISBN 978-0815316190
  - A significant portion of the class will consider the physics of polymers. An excellent book is: *Scaling Concepts in Polymer Physics* by P.-G. de Gennes, Cornell University Press. ISBN 978-0801412035
  - A similar course is offered via MIT OpenCourseWare[1] *Statistical Physics in Biology* by Mehran Kardar and Leonid Mirny
  - See the instructor for many opinions about textbooks on this topic.
- This class is a good opportunity to learn the LaTeX typesetting system for generating nice-looking equations. A good free distribution for Windows is MiKTeX (`https://miktex.org/`). Mac OS and Linux both have TeX Live (called MacTeX for Macs). See `https://www.latex-project.org/get/` for more information on how to download these packages. Feel free to ask the instructor about help to set this up.

Homework Assignments

Homeworks will be assigned roughly one time every two weeks. The homeworks will be due on Mondays at the start of class. *Physical* copies must be turned in to the instructor at the beginning of the lecture. Homework submitted after the deadline *will not count. Exception:* Students who are typesetting their homework using LaTeX will receive an extra 48 hours to complete the assignments. They may turn their homework in electronically by the start of class on Wednesday via e-mail to the instructor (pdf and TeX formats).

[1] `https://ocw.mit.edu/courses/physics/8-592j-statistical-physics-in-biology-spring-2011/`

Remember that these assignments will constitute the most important component of the course. Please take your time and put down as many details as possible for the problems. Partial credit will be awarded for demonstrating a correct train of thought. On certain homework assignments, extra credit opportunities will be available.

Quizzes and Presentations

Short quizzes (roughly 5 minutes and typically in multiple choice format) will be given in the beginning of some lectures covering the previous lecture material. These are intended to make sure you are regularly attending the lectures and following the class material. There will also be some in-class presentations where you will present either a problem or a paper, similar to a scientific journal club.

Exam

The final exam will be a take-home exam and will be due some time *before* the official final exam period, which is 10:15 AM-12:15 PM on Wednesday, December 12 in Nielsen 512.

Grades

The homework is the most important component of your success in the course. The grade distribution reflects this philosophy.

Grade Distribution	
Homework	50%
Quizzes/Presentations	20%
Final Exam	30%

Letter Grade Distribution			
$\geq$ 90.00	A	70.00 - 72.99	C
87.00 - 89.99	A-	67.00 - 69.99	C-
83.00 - 86.99	B+	63.00 - 66.99	D+
80.00 - 82.99	B	60.00 - 62.99	D
77.00 - 79.99	B-	57.00 - 59.99	D-
73.00 - 76.99	C+	$\leq$ 56.99	F

Note that in some tests and homework assignments, a scaling may be applied. The scaling will not lower your grade.

Announcements

Please check the Canvas site for the course regularly for announcements and postings!

Academic Integrity

Working together on homework assignments and discussing with classmates outside of class is encouraged! However, work you turn in should be your own. Please take the time to demonstrate your own thoughts about the solutions and derivations. This is in keeping with the university honor statement:

> An essential feature of the University of Tennessee, Knoxville is a commitment to maintaining an atmosphere of intellectual integrity and academic honesty. As a student of the university, I pledge that I will neither knowingly give nor receive any inappropriate assistance in academic work, thus affirming my own personal commitment to honor and integrity.

Accommodations

Please contact the instructor about any concerns! The official statement on accommodations is:

> Any student who feels s/he may need an accommodation based on the impact of a disability should contact Student Disability Services in Dunford Hall, at 865-974-6087, or by video relay at 865-622-6566, to coordinate reasonable academic accommodations.

Additional contact information:

Disability Services
915 Volunteer Blvd/100 Dunford Hall
Knoxville, TN 37996-4020
e-mail: `ods@utk.edu`
website: `http://ods.utk.edu/`

Tentative Schedule of Topics

Weeks (dates)	Topic	Relevant Chapters
1-2 (08/22-08/31)	introduction to the cell, DNA/RNA, central dogma, basic probability theory	1-3 (PBC), 1-2 (MDF) 3-5 (PMLS)
3-4 (09/05-09/14)	single molecule biophysics, random walks, freely-jointed chain, spin models	7-8, 11 (PBC), 1-2 (MDF), 8 (PMLS)
5-6 (09/17-09/28)	solutions, polymer mixtures, phase separation, lattice models	5-6, 13-14 (PBC), 15, 25, 31-32(MDF)
7-8 (10/01-10/12)	chemical kinetics, Fokker-Planck equation, diffusion over a barrier, molecular motors	15-16 (PBC), 18-19(MDF), 7 (PMLS)
9-10 (10/15-10/26)	transcription, gene regulation, lambda phage, lac operon, MWC model	4, 19 (PBC), 26-29 (MDF), 9 (PMLS)
11-12 (10/29-11/09)	transcription network dynamics, network motifs, random networks	19 (PBC), 9-11 (PMLS)
13-14 (11/12-11/21)	cell birth and death, number fluctuations, Gillespie algorithm	19 (PBC), 18 (MDF) 8 (PMLS)
15 (11/26-12/03)	spatial population genetics, evolution, Fisher waves, pattern formation	20-21 (PBC)