PHYS 444 – Physical Biology: From Molecules to Cells
Fall 2021
Course Information

1. Introduction:

When: Class Wednesdays/Fridays 12:00 – 1:50 pm. Office Hours TBD
Who: You and me (Peter Chung, pjchung@usc.edu, SSC 211B)
Where: KAP 137, Office Hours TBD
What: An introductory biological physics class. Our text will be *Physical Biology of the Cell, 2nd edition, by Phillips, Kondev, Theriot, and Garcia*. You can find it at the bookstore, or get it somewhere online.
Prerequisite: PHYS 152 or PHYS 162
Recommended Preparation: A background in cell biology is recommended, but not required.

2. Course Description

The last few decades have witnessed historical advances in cell, molecular, and structural biology. As new experimental measurements and techniques emerge, this has become fertile ground for physicists to explore fundamental laws and organizational principles behind biology.

This 4-unit course bridges the "No Man's Land" between the quantitative modeling of idealized systems that physics students are typically exposed to, and the complexity of real cell biology that biologists appreciate. This course is now the cornerstone of the undergraduate biophysics major and the jumping off point for Physics and Physical Biology PhD students. **More than any physics course, success in Physical Biology is a function of enthusiasm and dedication to the material than any inherent ability.**

The course's blackboard page will be routinely updated to point to the corresponding chapters (or sections) from the *Phillips* book as well as any additional reading (see below). Please note that this list is subject to changes and tweaks throughout the semester – depending on the level of interest and student response, we may choose to delve more deeply into certain topics.

- The basic components and construction plans of life. Length, time, and energy scales of life.
- Order of magnitude estimates in biology
- Case studies of quantitative model building in biology
- Thermodynamics in biology (can we invoke equilibrium?)
- Statistical mechanics in biology: predicting equilibrium, two-state systems, ion channels, cooperative binding, random walks, and biomolecular structures
- Electrostatics of salty environments
- Beam theory of cellular structure
- Biological membranes
- Life far from equilibrium: motility, dynamics, rate equations, molecular motors, bioelectricity
- Electron transfer theory & metabolism: respiration, lithotrophy, and phototrophy
- Final projects: Current problems from the biophysics literature.

3. Books, Supplementary Reading, and Guest lecturers

The textbook by Phillips *et al* is a pedagogical triumph. The book's organization sets it apart from all other books on the subject. While most authors organize topics according to biological function, our textbook presents similar information organized based on their proximity in the physical biology / quantitative modeling perspective. Most topics follow a familiar pattern: 1) Introduce a problem, 2) Make an order of magnitude estimate, 3) Propose a crude (but quantitative model), and 4) Refine the model to the point where it matches biological observations with the hope that it serves as a *predictive* model.

We will stick closely to the book in the first few weeks of the semester. However, it is critical that you read the book as we go along. The book aside, this is a reading intensive class. I will post reading assignments from current and classical literature as we go along. In addition, I will routinely point you to a number of books for either an interesting take on biophysics, or an in-depth treatment of specific topics:

B. Alberts, D. Bray, A. Johnson, J. Lewis, M. Raff, K. Roberts and P. Walter, *Essential Cell Biology*, Garland Publishing, 2003. A great reference book.

D. Boal, *Mechanics of the Cell*, Cambridge University Press, 2001. Boal has assembled a very nice collection of insights into the ways in which mechanics can be applied to the living world.

K. Sneppen and G. Zocchi, *Physics in Molecular Biology*, Cambridge University Press, 2005. This book is one of a growing number of attempts on the part of physicists to make a case for the role of quantitative analysis and physical reasoning in attacking real biological problems. There are many interesting topics scattered throughout the book.

S. Carroll, *Endless Forms Most Beautiful*, W. W. Norton and Company, 2005. An absolutely amazing treatment.

M. Kirschner and J. Gerhart, *The Plausibility of Life*, Yale University Press, 2005. This book is similar in spirit to that of Carroll and discusses the insights that modern molecular and developmental biology have provided into evolution.

A. Murray and T. Hunt, *The Cell Cycle*, Oxford University Press, 1993. This book is by two of the leaders in this field and, though it is probably dated, it is full of interesting facts and ideas.

J. Howard, *Mechanics of Motor Proteins and the Cytoskeleton,* Sinauer Associates, 2001.

O. Mouritsen, Life - *As a Matter of Fat*, Springer, 2005. This book gives a number of insights into the role of lipids.

R. Burton, *Physiology by Numbers*, Cambridge University Press, 2000. This book attempts to take stock of many of the processes of physiology from the perspective of "a feeling for the numbers", as we will do in the class.

R. Schleif, *Genetics and Molecular Biology*, Johns Hopkins University Press, 1993.

P. Nelson, *Biological Physics: Energy, Information, Life,* W. H. Freeman and Company, 2004. Phil Nelson's book represents a view of parts of biology from a fully quantitative perspective and makes for enlightening reading.

Ptashne, M., *A Genetic Switch*, Blackwell Science, 1992 and Ptashne, M. and Gann, A., *Genes and Signals*, Cold Spring Harbor Laboratory Press, 2002. Absolutely amazing. The clarity of the thinking and the far-reaching vision which attempts to tame the complexity of biological specificity is truly inspiring. **I also encourage you to listen to Ptashne's lectures at Rockefeller University which you can find online**.

Dill, K. and Bromberg, S., *Molecular Driving Forces*, Garland Publishing, 2002. This fantastic book gives a proper description of the power and versatility of statistical mechanics as opposed to the schoolboy exercises that make for the main substance of most books on statistical mechanics. The applications to real world problems in biology and chemistry are as refreshing as they are enlightening (Note from ME-N: I use this book occasionally in my undergraduate statistical thermodynamics class, and the physics majors love it)

Carroll S. B., Grenier J. K. and Weatherbee, S. D., *From DNA to Diversity*, Blackwell Science, 2001. This book is of the same high quality as those by Ptashne (and indeed, was inspired by Ptashne's *A Genetic Switch*). Like Ptashne, these authors try to follow one key idea to its extreme, namely, the idea that animals share the same "genetic toolkit" that dictate body pattern.

G. Fain, *Sensory Transduction*, Sinauer Associates, 2003. Fain's book describes how organisms take external stimuli and do something with it. Two related books that will touch on the processing of information are G. Matthews, Cellular Physiology of Nerve and Muscle and M. Blaustein, J. Kao and D. Matteson, Cellular Physiology.

A. Lesk, *Introduction to Bioinformatics*, Oxford University Press, 2002. Want to know the differences between wooly mammoths and elephants, etc? Read this book.

A. Y. Grosberg and A. R. Khokhlov, *Statistical Physics of Macromolecules*, AIP Press, 1994. Full of interesting insights into the ways in which polymer physics can be used to explore problems of biological interest.

J. M. Berg, J. L. Tymoczko and L. Stryer, *Biochemistry*, W. H. Freeman and Company, 2002. There are a host of interesting books on biochemistry and the hope is that you will overcome any distaste you might have for the mindless memorization that seems to dictate the pedagogy that many of us have been exposed to, and be open to the many beautiful problems in this area.

I. M. Klotz, *Ligand-Receptor Energetics*, John Wiley and Sons, 1997 and *Introduction to Biomolecular Energetics*, Academic Press, 1986. Like Ptashne, Klotz brings personality, originality and clarity to his books. Klotz works very hard to teach us how to think about molecules in interaction, and as he points out in the preface, it is only when viewed through the prism of their interactions that molecules are of interest to life.

J. D. Watson, T. A. Baker, S. P. Bell, A. Gann, M. Levine and R. Losick, *Molecular Biology of the Gene*, Cold Spring Harbor Laboratory Press, 2004.

E. Bier, *The Coiled Spring: How Life Begins*, Cold Spring Harbor Laboratory Press, 2000.

J. Israelachvili, *Intermolecular and Surface Forces*, Academic Press, 1992. The subject of this book is much larger than is implied by the title. We will make reference to Israelachvili's discussion both when discussing forces in the material world and also in the context of self-assembly.

C. R. Calladine and H. R. Drew, *Understanding DNA*, Academic Press, 1999. This book provides a window on DNA which makes a good deal of contact with the perspective that will be brought to this important molecule in the course.

M. Doi, *Introduction to Polymer Physics*, Oxford University Press, 1996. This book is short and sweet and provides a readable introduction to many of the ideas from polymer physics that we will borrow in our attempt to understand the mechanics of biological macromolecules.

P.-G. de Gennes, *Scaling Concepts in Polymer Physics*, Cornell University Press, 1979. de Gennes classic epitomizes the appeal of "universal" insights.

A. Y. Grosberg and A. R. Khokhlov, *Giant Molecules*, Academic Press, 1997. A very nice introduction to the physics of macromolecules. Describes many of the arguments that will be made in our course.

U. Seifert, *Configurations of fluid membranes and vesicles*, Adv. Phys., 46, 13 (1997). Seifert provides a detailed description of the elasticity of membranes as well as insights into the current understanding of equilibrium shapes.

H. C. Berg, *Random Walks in Biology*, Princeton University Press, 1993. **A must read**. Berg has all sorts of fun and interesting things to say.

M. Doi and S. F. Edwards, *The Theory of Polymer Dynamics*, Clarendon Press, 1986. Doi and Edwards have some important discussions of the motion of polymers in crowded environments.

H. Echols, *Operators and Promoters* and H. F. Judson, *The Eighth Day of Creation.* Two very interesting books on the history of molecular biology. Judson's book is instructive both on the science and on the types of personalities that did that science. Echols was a molecular biologist himself and tells the story of the development of molecular biology in very compelling terms - if you read this book you will learn much biology.

To the extent possible, I will be inviting special guest lecturers throughout the semester to give you special insight into current research topics. I hope you will enjoy these appearances.

4. Demonstrations

Biophysics is advancing rapidly, mostly because of experiments. Throughout the course, I will constantly explain and refer to experimental techniques. In addition, I will hopefully organize a few experimental demonstrations using my own laboratory at USC. I hope this will give you a unique flavor of experimental biophysics.

5. Online Course Support

The PHYS 444 home page is maintained at http://blackboard.usc.edu. Under the home page you will find a copy of this course syllabus, lecture slides, assigned reading (***check it every week***), solutions to problems discussed in class, current homework assignments together with some hints, homework solutions, handouts, grades and perhaps other information.

6. Homework Assignments

Homework assignments complement the lectures and constitute an integral part of this course. **They're weighted quite heavily in this course (60% of the total grade).** The solutions to the written assignments are due on Blackboard **before** Wednesday lecture. Do not bother trying to hand in a late homework assignments. If for a *strong* reason you are unable to finish your homework on time, send me an e-mail and ask for an extension **before the homework is due.**

Please talk to your colleagues and classmates as you work on problem sets. The solutions should be written up legibly with enough details so that anybody, not just the author, can understand what is going on. Specifically, be sure to show all intermediate steps and use words, not just equations, to explain the solution. A solution consisting of a string of equations with no comments will be considered unsatisfactory. Finally, please note that you are not allowed to look up solutions in a solutions manual or on the web. Graded homework will be returned in class and solutions will be posted on the course home page.

7. Final Project (Summative Experience)

During the last few weeks of classes, you will be organized into teams. Each team will work collaboratively on one of the serious/longer problems in the textbook, or some other problem of my choosing (preferably an open-ended serious problem of current interest in the field i.e. current scientific literature). Alternatively, if some random problem tickles your interest, run it by me. If I like it as well, we can discuss making it into a project. You will then work out the details, submit a professional-quality final report, and make a presentation to the class on the results, as well as a nice poster. I'll provide more details on project topics and logistics by the middle of the semester. The point is to have fun, work in a team, and get into some serious research problem that we can all explore together

8. Grading

The final course grade will be determined according to the following distribution:

Homework	**60%**
Project	**20%**
Class participation	**20%**

Class participation is essentially about you being involved in class. I will teach this class seminar style, and it has to be a two-way street. Letter grades are entirely at my discretion i.e. I do not use rigid percentage marks (such as e.g., a rule that 90% would correspond to A- or similar). Further details about the grading procedure are given in class.

9. Miscellaneous

Academic Integrity

Students who violate university standards of academic integrity are subject to disciplinary sanctions, including failure in the course and suspension from the university. Since dishonesty in any form harms the individual, other students and the university, policies on academic integrity will be strictly enforced. We expect you will familiarize yourself with the USC academic integrity guidelines.

The Trojan Integrity Guide (A Guide to Understanding and Avoiding Academic Dishonesty) can be found at

https://sjacs.usc.edu/files/2015/03/tio.pdf

The Undergraduate Guide for Avoiding Plagiarism can be found at

https://sjacs.usc.edu/files/2015/03/tig.pdf
A Guide for Graduate Students can be found at
https://sjacs.usc.edu/files/2015/03/GradIntegrity.pdf

Students with Disabilities

Any student requesting academic accommodations based on a disability is required to register with Disability Services and Programs (DSP) each semester. A letter of verification for approved accommodations can be obtained from DSP. Please be sure the letter is delivered to me or the TA as early in the semester as possible. DSP is located in GFS 120 and is open 8:30 a.m. – 4:30 p.m., Monday through Friday. The phone number for DSP is (213) 740-0776.

10. Important Dates

Labor day: Monday, September 6
Fall Recess: Thursday-Friday, October 14-15
Thanksgiving: Wednesday-Sunday, November 24-28

11. Faculty Liaisons

All classes in the Department of Physics & Astronomy have an assigned Faculty Liaison to serve students as a confidential, neutral, informal, and independent resource when they wish to discuss issues concerning their course without directly confronting their instructor. The Faculty Liaison for this class is Dr. Jack Feinberg, feinberg@usc.edu, 213-740-1134, SSC 327

12. COVID-19 Requirements

Students are expected to comply with all aspects of USC's COVID-19 policy. Failure to do so may result in removal from the class and referral to Student Judicial Affairs and Community Standards.