Syllabus PHY 615 Biological and Medical Physics Fall 2007

Introduction: It is my pleasure, on behalf of the Department of Physics, to welcome you to **Biological and Medical Physics**. This course is designed to build the solid foundation in Biological Physics that is necessary to further your deep understanding of any biomedical discipline. **What is biological physics or biophysics?** It is a discipline that uses the concepts and tools of physical chemistry and molecular physics to define and analyze the structures, energetics, dynamics, and interactions of biological molecules. This research is also leading to designs of new classes of instrumentation for use in the fields of genomics, proteomics, drug delivery, biosensors and clinical diagnostics. Traditionally, biophysics has been defined as an application of various methods and principles of physical science to the study of biological problems. This course is a broad survey of "biological and medical physics" and its applications to emerging arenas, such as chemical biology, molecular medicine and medical biotechnology, with an emphasis on the concept of energy, and transport of matter in biological systems.

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Phone: 315-443-8078 (Office); 315-443-0249 (Lab); Office: Room 211, Physics Building; Single-molecule Biological Physics Laboratory: Rooms B103/B105, Physics Bldg.; Do not hesitate to seek my assistance over the next few months and beyond.

Office hour: Tuesdays 2:00 – 3:00 P.M., otherwise by appointment.
I am often in my office (443-8078) or lab (443-0249). Please call me, if you have an emergent problem! You are most welcome to contact me by e-mail.

Prerequisite: There is no prerequisite for this graduate-level course.

Lectures: We will meet twice a week: Tuesdays and Thursdays, 11:00 A.M. – 12:20 P.M., Lectures will be held in Room B126 (The basement level), Physics Building. We introduce new ideas and concepts that are involved in classical and emerging fields of biological physics. We also invite some experts in the area of biological and medical physics from SU, SUNY-ESF, and SUNY Upstate Medical University. Most of the information, including the lectures, will be covered online at the following link:
http://www.physics.syr.edu/~lmovilea/BiologicalMedicalPhysics2005.html

Course calendar: The timetable will be always updated on the web site of this course:
http://www.physics.syr.edu/~lmovilea/BiologicalMedicalPhysics2005.html

Course overview:

Biological and Medical Physics (PHY 615, 3 credits) is a one-semester graduate level course intended for students from the physical, chemical, and biomedical sciences. Graduate students enrolled in the Structural Biology, Biochemistry and Biophysics Program (SB3), or those from the Biotechnology (SUNY – ESF) and

Biomedical Sciences Programs (SU) are very welcome. Note that this is not a course to teach either "biology for physicists" or "physics for biologists." Instead, the emphasis will be on selected "hot topics" that lie at the interface between physical, chemical, and biomedical sciences. The primary aim is to have an overview of fundamental biophysical research questions, as well as recent experimental developments and techniques that engage multidisciplinary efforts. In addition, we will discuss "applicative topics" of biological physics in several realms, including nanobiotechnology, biosensors, drug delivery, and medical imaging. Therefore, much of the content of PHY 615 will be presented in a nontraditional manner. Finally, from a practical point of view, this course will establish strategies for people with complementary backgrounds who are working, or who intend to work, in multidisciplinary areas. The particular subfields of biological and medical physics that we study in Physics 615 are the following:

1. Biological thermodynamics
2. Membrane biophysics & ion channels
3. Molecular biophysics
4. Cell signaling and cell biophysics
5. Single-molecule biophysics
6. Nanobiotechnology and biosensors
7. Modern experimental methods in Biophysics
8. Biomedical Imaging and Medical Physics

Please be aware that some of the subfields will be covered in more detail than others. The relative coverage of individual subfields will be balanced on the needs of the enrolled students. We are happy to have students enrolled from various majors/departments, including SU - Physics, SU - Biology, SUNY ESF - Chemistry, SU - Bioengineering, SB_3 Program (Structural Biology, Biochemistry, and Biophysics), and SUNY Upstate Medical University.

Goals for the Course: What should you be getting out of your PHY 615 experience? My goals are for you to:

- Understand the modern fundamental questions in Biological and Medical Physics;
- Gain the skills to solve biophysical problems and to be able to identify a variety of relevant biophysical phenomena in your own research;
- Acquire many of the skills necessary for critical thinking. This will be accompanied by a deeper understanding of the spirit of scientific reasoning;
- Get communication skills in an interdisciplinary environment to solve fundamental problems that require complementary expertise.

These are, of course, broad goals. More primary aims in Biological & Medical Physics are listed on the web page of this course.

Textbook: There is no ideal textbook for Biological and Medical Physics course, at the graduate level. We will use sections from different textbook sources or specific review papers. Hands-out will be provided at the time or before the lecture.

Grading Policy: You will be evaluated, based upon your commitment and accomplishments in this class. Grading will be based on homework, presentations/reports, and the final exam. Problems will be assigned as homework either taken from the lecture material or from the textbook. A presentation will be made by each student toward the end of the semester on a topic of choice by mutual agreement between the student and the instructor. The presentation will be accompanied by a written report. A comprehensive final exam will be given at the end of the semester. This exam will cover all the material in the course. You will be evaluated, based upon your participation during the class (30%), your homework (10%), your report (30%), and your final exam (30%). From the net numerical grade, a letter grade is computed. The grade limits will not be stricter than the following: 70% for a C- minus, 80% for a B-, and 90% for an A-.

Report guidelines:
- Description of topic in less than 4,000 words; the topic should be different from your own field of research!
- Literature-search-based description of the topic; this should include an outline of the features of interest, current challenges of the topic, relevance of the features to the topic, an explanation of why it works the way it does and how it works, and a closing statement/paragraph. The closing statement should include the description of unresolved problems and future prospects.
- When the topic concerns a scientific principle, include parameters and calculations of elementary physical properties; e.g., speed of propagation, index of refraction, forces, velocities, pressures/pressure gradient, assumptions made, etc.
- Use SI units (System International), such as meter [m], kilogram [kg], second [s], and derivatives (Newton [N], Celsius [^{0}C]/Kelvin [K], Volt [V], Ampere [A], Joule [J], Watt [W], Pascal [Pa], Coulomb [C], etc.
- Include images/graphs where appropriate.
- List, and refer to, all consulted articles and books.
- Submit your report in MS-Word.

Exam: A comprehensive final exam will be given at the end of the semester. This exam will cover all the material in the course. The date of the final exam is Friday, December 14th, 2007, 8:00 A.M. – 10:00 A.M., Room B126, Physics Bldg. No make-up exams will be given.

Homework: The homework assignments will be distributed weekly. Homework will be normally due on the lecture scheduled on the following week. Solutions to the homework will be distributed after the problems have been collected. Working problems is the only way to obtain a deep clarification of each topic.

Course secretary: Ms. Arlene Johnston (Phone: 443-1915) is available in Room 111, Physics Building, from 8:00 A.M. to 4:30 P.M. weekdays. She is the person to see for signatures on add/drop forms, or for other administrative matters. If she is ever unavailable, please go to the Main Office of the Physics Department, Room 201, Physics Building, for assistance.

TENTATIVE TOPICS IN BIOLOGICAL AND MEDICAL PHYSICS (PHY 615)

1. Biological thermodynamics

How do transition-state rates relate to kinetic models?
What is the difference between equilibrium and nonequilibrium thermodynamics?
What is the relationship between kinetics and thermodynamics?

2. Membrane biophysics, neurophysiology, ion channels, and ion pumps

How do lipid rafts organize and behave in a cell membrane?
How does a membrane protein fold in a hydrophobic environment?
How does a cell membrane function?
How do the biopolymers (DNA, proteins) translocate through protein channels?
How do the thermoreceptors (cold and warm) function?

3. Single-molecule biophysics and biopolymers (molecular biophysics)

Why do we have to study biological processes at the single-molecule level?
How does entropically-driven folding of biopolymers appear in nature?
What are the energetic barriers that must be overcome to unfold a protein, or an RNA molecule?
Why does DNA like to bend, but not to fold?
How do molecular motors function?
How does thermodynamic stability differ from mechanical stability?

4. Cell signaling

How do sensory receptors make electrical signals?
Why is mechanotransduction rapid and direct?
Why is visual transduction slow?
Why and how does vertebrate phototransduction use cyclic GMP?
How do second messengers stimulate ionic transport?
How does pain sensation use transduction channels?
How do we define an excitable cell?

4. Nanobiotechnology and biosensors: Prospects of applied biophysics in nanotechnology

What are the primary aims of nanobiotechnology?
What are the risks of nanobiotechnology?
Why do we have to reduce the experiment to the *lab-on-chip* platform?
Why does DNA have to be identified at the single-molecule level?
What is the efficiency of DNA chip arrays to detect pathogens?
Why do we need protein nanoarrays and protein engineering?
What can we learn by using natural and synthetic nanopores?

5. Other Modern Experimental Methods in Biophysical Nanotechnology

How does an atomic force microscope work?
How do the single-molecule tweezers (optic or magnetic) work?
How does a single-molecule fluorescence microscope work?
How does a total internal fluorescence microscope work?

Recommended textbook for PHY 615

1. Nelson, P. (2004) Biological Physics. Energy, Information, Life. W.H. Freeman and Company, New York.
2. Haynie, D.T. (2001) Biological Thermodynamics. Cambridge University Press, Cambrdge.
3. Nölting, B. (2004) Methods in Modern Biophysics. Springer-Verlag, Berlin Heidelberg New York.
4. Tuszynski, J.A. & Kurzynski, M. (2004) Introduction to Molecular Biophysics. CRC Press, Boca Raton.
5. van Holde, K.E., Johnson, W.C. & Ho, P.S. (2006) Principles of Physical Biochemistry. Prentice Hall, Upper Saddle River, New Jersey.
6. Hille, B. (2001) Ion channels of excitable membranes. Sinauer Associates, Inc., Sunderland, Massachusetts.
7. Hobbie, R.K. (1997) Intermediate physics for medicine and biology – Third Edition, from Biological and Medical Physics – Biomedical Engineering, AIP Press, Springer Science & Business Media, Inc., New York.
8. Daune, M. (2001) Molecular Biophysics – Structures in motion, Oxford University Press, Oxford, UK.
9. Serdyuk, I.N., Zaccai, N.R. & Zaccai, J. (2007) Methods in Molecular Biophysics, Cambridge University Press, Cambridge, UK.
10. Sneppen, K. & Zocchi, G. (2005) Physics in Molecular Biology, Cambridge University Press, Cambridge, UK.
11. Jackson, M.B. (2006) Molecular and Cellular Biophysics, Cambridge University Press, Cambridge, UK.
12. Forgacs, G. & Newman, S.A. (2005) Biological Physics of the Developing Embryo, Cambridge University Press, Cambridge, UK.
13. Poon, W.C.K. & Andelman, D. (2006) Soft Condensed Matter in Molecular and Cellular Biology, Taylor & Francis, New York London.
14. Boal, D. (2005) Mechanics of the Cell, Cambridge University Press, Cambridge, UK