Topics in Biophysics (3 credits for undergraduate students and 4 credits for graduate students)

Department of Physics, Universidad de los Andes
Course code: FISI4882 (graduate) y FISI3882 (undergraduate)
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Office hours:
Guide Texts: Biological Physics, Energy, Information, Life. Philip Nelson, Updated First Edition
Thermal Biophysics of Membranes, Thomas Heimburg.
Physical Biology of the Cell, Phillips, Kondev, Theriot, Orme.

Course Instructors: Chad Leidy (Department of Physics).

I. Description of the Course

What is Biophysics?

Biophysics is the field that applies the theories and methods of physics to understand how biological systems work. Biophysics has been critical to understanding the mechanics of how the molecules of life are made, how different parts of a cell move and function, and how complex systems in our bodies—the brain, circulation, immune system, and others— work. Biophysics is a vibrant scientific field where scientists from many fields including math, chemistry, physics, engineering, pharmacology, and materials sciences, use their skills to explore and develop new tools for understanding how biology—all life—works.

In this course, we will begin by introducing the basic theoretical theories that biophysicists apply to do their work. In the second half, we focus our attention on cell membranes, which are fascinating biological assemblies with interesting properties and important physiological functions. These complex structures protect cells from outside conditions, and help the cell communicate with outside world, and respond to external factors. Their complexity and importance in cell processes makes them an interesting topic of study for the second part of this course.

Objective of this course

In this course, we will introduce students (coming from different fields, including physics, chemistry, biology, math, engineering) to the following main ideas:

a) Biological structures and the relation between structure and function for the main biomolecules.

b) The basic biophysical theory used to quantify and understand the behavior of biological systems, including free-energy and equilibration, reaction kinematics, diffusion, and electrostatics in electrolyte solutions.
c) The basic experimental and computational techniques used to observe, measure, and quantify the biophysical processes.
d) Theoretical concepts related to biological membrane assemblies, such as phase transitions, phase coexistence, binding isotherms, membrane mechanical properties, and membrane fusion.

Learning objective:
At the end of the course, students will be able to:

a. Describe molecular and structural aspects of biological molecules and their function in cells.
b. Be capable of analyzing the behavior of biological systems using basic concepts in thermodynamics, statistical physics, electrostatics, and diffusion theory.
c. Identify the basic experimental and computational techniques needed to study biological membranes.
d. Narrow down a scientific question in biophysics and write a research proposal regarding the proposed question.

II. Prerequisites

1) Thermodynamics or equivalent. Students that have taken Physical Chemistry may take the course.

III. Evaluation system

Activities and points (3 credits)

1) **(35%) Homework.** Four homework assignments will be turned in throughout the semester. The homework assignments will include problems from Nelson.
2) **(5%) First draft of essay analyzing a research publication in biophysics.** The student will chose a research publication in a biophysical journal to analyze. The student needs to introduce the topic, describe and discuss the findings. This first draft only identifies the paper and presents a small introduction of the general topic.
3) **(40%) Two Midterm Exams.** Students will be required to write explanations about certain concepts covered in class.
4) **Final presentations and final research projects.**

a) **(10%)** Students will give brief 10 minute presentations of their research proposals during the time slot allocated for the final exam.
b) **(10%)** Final version of the essay (maximum 6 pages). The final version of the research proposal will include the following sections:
   i) Introduction to the topic
   ii) Description of results including a description of experimental, computational or theoretical techniques used.
   iii) Description and discussion of results.

Activities and points (4 credits)

5) **(20%) Homework.** Four homework assignments will be turned in throughout the semester. The homework assignments will include problems from Nelson.
6) **(10%) First Draft of Research Proposal.** These research proposals are written in teams of two students, and in English. Write the proposal using the rules of an R03 grant from the National Insitute of Health (6 pages maximum). This first draft is only a dirty outline of the grant, including the topic of research, an initial draft of its significance and innovation, an outline of the aims with brief descriptions, and some bibliography.
7) **(40%) Two Midterm Exams.** Students will be required to write explanations about certain concepts covered in class.
8) **Final presentations and final research projects.**
   c) **(10%)** Students will give brief 10 minute presentations of their research proposals during the time slot allocated for the final exam.
   d) **(20%)** Final version of the research proposal. The final version of the research proposal will include the following sections:
      iv) Specific Aims with extended descriptions.
      v) Significance. General description of why the topic is important
      vi) Innovation. Why will this proposed research provide a significant advancement in this problem or field of research.
      vii) Approach. A more careful description of the experimental, computational, or theoretical methods used to address the specific aims.

(Entrega del 30%) more than 40% of the total grade will be turned in at the end of week 8, which includes grades for HW 1 and 2, preproposal or essay, and 20% from Midterm #1.

IV. Week to Week activities.

Week	Readings	Topic
1	Nelson 2.1.1 to 2.1.2	Description of program and a tour through the cell, cell organization, the cell membrane, energy production machinery, cytoskeleton, transport, protein synthesis.
2	Nelson 2.2.1-2.3.4	From chemical structure to cell function. Biological structures and their role in the cell. The lipid bilayer, DNA, RNA, Proteins.
3	Nelson 6.2.1-6.6.4	The Boltzmann distribution, free energy of Gibbs and chemical equilibrium. Energy barriers and reaction rates.
4	Nelson 8.1.1 to 8.6.2	Self-assembly in biomolecular systems. Energy minimization during protein folding and membrane assembly. Enzyme kinetics. Molecular dynamic simulations.
5 **HW #1 due**	Nelson 10.1.1 to 10.4.4	Entropic forces at work. Molecular motors. Bacterial Cell division as a model for molecular force generation. Measuring biological forces through atomic force microscopy.
6	Nelson 7.1 to 7.3	Chemical potential in the production of ATP, electrochemical potential and ion gradients, osmotic pressure.
7	Nelson 7.4 to 7.5 Heimburg 11.1 to 11.7	Electrostatic interactions in biological systems. Diffuse Double Layer and Gouy-Chapman Theory. Debye length. Attractive interactions in biological systems.
8 **HW #2 due. Preproposal is due.**	Nelson 3.1 to 3.3 Heimburg 10.1 to 10.4	Brownian motion and Diffusion theory. Diffusion limited signaling. Diffusion in membranes, Montecarlo techniques, Fluorescence Recovery after Photobleaching, Correlation spectroscopy, Single molecule particle tracking. **Midterm #1 (cell biology, free energy, kinematic analysis, electrostatics)**
9	Heimburg Chapter 1-3	Membrane structure and the composition of biological membranes.

10	Heimburg Chapter 6	Lipid melting and phase transitions. Calorimetry, extensive parameters of membranes and their behavior during phase transitions
11	Heimburg Chapter 7	Phase diagrams, regular solution theory and the role of lipid domain formation in cell function.
12 **HW #3 due**	Heimburg Chapter 9	Adsorption, Binding and insertion of proteins to membranes.
13	Heimburg Chapter 9	Antimicrobial peptide activity and *de novo* design of novel membrane targeted antibiotics.
14	Heimburg Chapter 13	Elasticity and curvature in cell membranes. Energy barriers in membrane fusion. Energetics of cell division.
15	Nelson Chapter 12 Heimburg Chapter 18	Nerve pulse propagation. Hodgkin-Huxley model and the action potential. **Midterm #2 (Membrane structure, phase transition, phase coexistence, protein membrane interactions and membrane mechanics)**
16 **HW #4 due**		Final presentations